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Evaluating the London Science Museum's Activity Boxes at UK STEM Clubs

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Abstract

The London Science Museum has developed activity boxes that contain resources for science club teachers to conduct exciting science activities. This project evaluated three activities at six science clubs. Overall, the activity boxes are successful. Interviews and observations showed that students and teachers enjoyed the activities, despite some problems including that instructions were difficult to follow and some activities did not function as planned. We corrected many of these flaws and provided guidance for future resource developers.

Acknowledgements

We could not have done this project without the help and guidance of our liaisons Libby Burkeman and Anna Phlippen. We would also like to thank our advisors Dominic Golding and Paul Davis for their helpful advice and feedback. We would like to send our thanks to the teachers and students at the six clubs we traveled to. Their feedback was essential to the success of this project. We would like to thank the museum staff members who took time out of their busy schedules to attend our focus group: Beth Hawkins, Richard Pering, Nora Maddock, Jane Dowden, Damien Arness-Dalton, and Andrew Dand. Thanks are in order for Teresa Teixeira from the Audience Research Team for providing excellent advice for evaluation. Tim Hawkins took many excellent photos that we used in our project. We are appreciative of Nicola Upton-Swift, Sarah Wren, Sam Spicer, and Maria Hogan in the Resources, Courses, and Visits Department of the Science Museum for their help and hospitality in their office.

Executive Summary

The London Science Museum has long been an institution dedicated to raising the public's interest in science and technology. While many people think of a museum as just a building with objects on display, the Science Museum has taken a more proactive approach through extensive outreach to students and teachers. The Museum is currently developing a set of science activity boxes that science club teachers can use to conduct exciting activities for their clubs. The activity boxes contain rare and exciting materials that are needed for each activity. One example is a plastic hand that contains a gel that turns darker shades of purple depending on its exposure to ultraviolet radiation. The boxes also contain resources for teachers running the activity such as an introductory film, teacher notes, a poster, and a PowerPoint presentation. Figure 1 shows the materials included with the activities we evaluated.

Figure 1: Box contents

This project conducted a thorough evaluation of selected activities to determine teacher and student opinions and identify ways to improve the functionality and performance of the science boxes. These activities include the Swipe Card activity from the Crime Lab box and the Biodome and UV Detector activities from the Mars Mission box. A breakdown of the activities in each box with those pertaining to this project highlighted can be found in Figure 2.

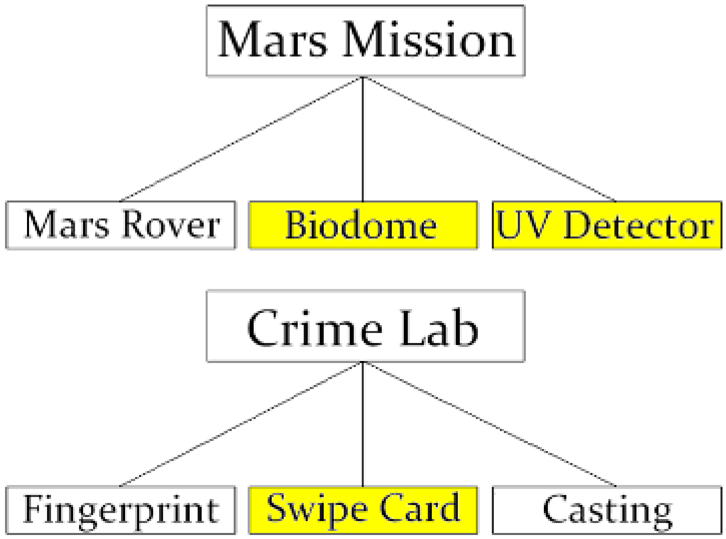

Figure 2: Activities included in boxes

Our findings include not only problems specific to the different activities we investigated, but also what constitutes an effective teaching resource. The major findings of this project include:

- There were significant problems with each activity's materials and instructions.
- Teachers want a resource that they can adapt to their teaching style and to the time constraints of their club meetings.
- The introduction of the activity is a critical time for capturing student interest.

Our recommendations to the museum include ideas for improving the boxes that can also be extended to future resources. These recommendations are ranked in order of importance as follows:

- Materials need to function correctly and instructions have to be clear and easy to understand.
- There should be plenty of options on how to run the activities for different teaching styles and time frames.
- The introduction for the activity needs to be exciting and motivate students to do the activity.

After discussing our recommendations with our liaisons at the Museum, we elected to fix several of the major problems we found with the boxes. We focused on the problems with materials and instructions that prevented the activity from functioning correctly. One example is that we developed new directions for the assembly of the plastic biodome for the Biodome activity. We also designed several new activities for the Science Museum based on our research into what makes a successful teaching resource. Each group member designed a new extension activity for the boxes. These extension activities addressed what students wanted to do and provided more opportunities for linking the activities to the curriculum. One activity we designed was the Mars Habitat Design Competition where students build a “habitat” out of common materials and compete against their classmates in a serious of tests that simulate conditions on Mars.

We had the opportunity to test our new ideas with a focus group of museum staff. These staff members were directly involved in designing teaching resources and provided useful feedback as well as new ideas to for improvement. Designing and testing our improvements and new activities allowed us to expand on the lessons learned from our project and deliver more to the museum than originally intended.

Although the boxes were generally well-received by students, there were significant problems with each activity. The recommendations that we have presented will not only allow the museum to fix these problems, but also provide insight on how to design new teaching resources. We have designed new activities from our findings and successfully tested them with experienced museum staff. Designing a new activity is a difficult enterprise, but having our research at hand helped immensely. Hopefully the museum will use our findings to not only improve the boxes, but also take them into consideration when designing future teacher resources.

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1. Introduction

Scientific progress and economic growth in Britain are threatened by a shortage of well-qualified engineering and science students. In 2005 a BBC report revealed that the number of students taking A-level physics had dropped by 34% from 1991 to 2004. The number of students taking A-level chemistry and math had fallen by 16% and 22%, respectively, over the same period (BBC, 2005).

One tactic in the battle to reverse these trends is to engage younger students' interest in science through enjoyable, hands-on activities. Studies such as those performed by Catherine H. Crouch have shown that students who are engaged in hands-on science activities understand core concepts better and are more interested in the material (Crouch, 2004). In an effort to address this problem, a British government program provided funding to about 250 schools to create science and engineering clubs.

A major challenge for the new science clubs is the lack of effective teacher resources. To address this need, the Science Museum in London has begun the development of a set of science activity 'boxes'. The boxes can be purchased by teachers for use in science clubs. The boxes provide age-appropriate activities and all the necessary materials and instructions to conduct them. To date, the museum has developed two prototype science boxes (Mars Mission and Crime Lab). While informal feedback has been positive, the boxes had not previous been evaluated formally in a club setting. This project improved these Science Museum's teaching resources by conducting a formal evaluation of three activities to gauge the performance of the boxes, identifying successes and failures, recommending improvements, and implementing some of those improvements.

Overall, we found that these boxes are welcomed enthusiastically by students and teachers. However, some of the materials failed to perform as expected, and teachers need better instructions and background materials. Nonetheless, with minimal modifications the boxes will become outstanding resources that teachers will feel comfortable using to raise their students' interest in science.

2. Literature Review

Improving the London Science Museum’s science boxes is part of the overall effort to change the current trends in science, technology, engineering, and math (STEM) learning. A study conducted by Warwick Institute of Employment Research between 2001 and 2007 projected an increase in the demand for individuals educated in the STEM disciplines between 2007 and 2017 (Warwick, 2009). The Organization for Economic Co-Operation and Development (OECD) released a Science Forum Policy Report in 2006 indicating an increase in overall number of students entering higher education in industrialized nations, but a smaller proportion entering the fields of science and technology over the past 15 years. Part of the reason is the view of careers in these fields. Many students have an incorrect idea of what STEM careers entail, typically using negative stereotypes to define their perceptions. Poor educational experiences also contribute to negative perceptions of science and technology careers (OECD, 2006). As a result, the available workforce for STEM fields is inadequate to maintain a successful and vibrant economy. In response, the United Kingdom has taken action to modify formal and informal education of students in the STEM areas. Changes to the curriculum have been made to include more emphasis on STEM subjects. Museums are taking a larger role in educational outreach and new venues for education, such as science clubs for students, are being promoted. All of the methods serve to increase students’ interests and remedy the current trends in STEM.

2.1 Attempts to Enhance Educational Performance in the Classroom

The United States has realized the extent of its own decrease in science interest over the years. Standardized testing in the 1970s showed a decrease in proficiency in science and math. Even so, more emphasis was still placed on reading and writing on the national level. In order to focus on the tested subjects, school districts lowered the amount of math and science graduation requirements in the 1990s (Peterson and West, 2003). Over the last decade, the disapproval of the current education approach became more apparent and led to the creation of No Child Left Behind. This piece of legislation was introduced in early 2001 in hopes to improve current education standards, especially in math and science fields. The bill called for more accountability of schools and their districts, local control over education, information and options for parents and greater reliance on education methods proven by research (George, 2002). As a part of this initiative, teachers are encouraged to improve their skills and knowledge to better educate pupils.

One way to do this is to create partnerships with scientists, mathematicians, and engineers (107th Congress, 2002). This way, teachers can bring the most current practices and information into the classroom concerning STEM subjects. Through methods similar to these, the US hopes to improve proficiency in a breadth of subjects, especially science.

Like the United States, the United Kingdom has taken efforts to improve their curriculum. The United Kingdom recently implemented a ten year program called the "Science and Innovation Investment Framework" in 2004 (HM Treasury, 2004). As part of this initiative to foster economic growth through science, the National Curriculum has been substantially revised. "Belief in education, at home and at school, as a route to the spiritual, moral, social, cultural, physical and mental development, and thus the wellbeing, of the individual" (QCA: National Curriculum, 2008) is at the core of the Curriculum's values. The Curriculum aims to develop students into individuals who can continue to learn, use their skills to contribute to society and lead fulfilling lives. In particular, the entire curriculum is designed to develop the functional abilities and personal learning and thinking skills an individual needs to succeed in society and maintain positive careers. The British Educational system also utilizes cross-curriculum lessons to add relevance, depth and perspective to the students' education (QCA: National Curriculum, 2008).

The National Curriculum focuses on four key stages of development during a student's educational experience in the system. Our project focuses on Key Stage 3 (KS3) which includes years 7-9 and the 11 to 14 year old range as shown in Table 1 (QCA: National Curriculum, 2008).

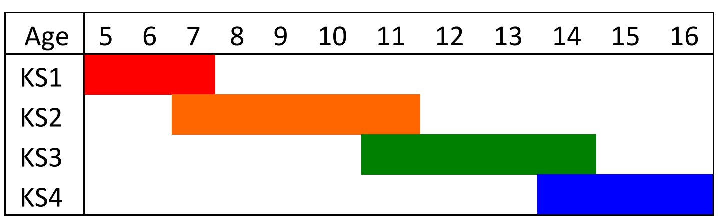

Table 1: Key stage (KS) age breakdown

Each key stage includes a specific set of subjects. KS3 encompasses the subjects of art and design, citizenship, design and technology, English, personal, social, health and economic education, religious education, geography, history, information and communication technology (ICT), mathematics, modern foreign languages, music, physical education, and science. The science components of KS3 have recently been modified to incorporate a stronger emphasis on the STEM subjects. The National Curriculum delineates the need for the development of scientific thinking, the applications and implications of science, cultural understanding, and the ability to collaborate across disciplines. Through the National Curriculum, KS3 students should research, inquire, and gain experience in the fields of electricity and other forms of energy and forces, chemicals and materials, organisms, and the environment (QCA: National Curriculum, 2008). Teachers often find that the formal learning put forth by the National Curriculum can be supported by visits to the museums. Museums often have interactive exhibits that relate to subjects of studies and can enhance a students learning experience.

2.2 Role of Museums and Informal Learning

Since the early 20th century the role of museums in society has changed. As views on education and the reasons for museum visits have changed, the museums themselves have needed to adapt. Museums have accepted that children require inquiry-based activities to get the most out of an educational experience. Additionally it has become known that most people visit museums to spend time as a family. These new ideas have been critical in a push towards utilizing different techniques to present desired information and exhibits.

For years, museums such as the Science Museum of London have been placing more emphasis on interactive learning to increase both visitor turnout and engagement. Research and experience has shown that children in particular enjoy and learn more through hands-on interaction, and museums have responded by adding hand-on exhibits and demonstrations. In his article on teaching methods, Shmaefsky emphasizes that there is a considerable body of research showing that students remember effective science demonstrations for years (Shmaefsky, 2009).

Interactive activities take many forms, but the basic focus is always to make the learner active in the learning process. Many different approaches are used to achieve this result, including allowing learners to handle artifacts and asking the learner to perform an experiment. The key element here however is that *they* are asking questions. Even the simple act of asking a learner to predict the outcome of an experiment before it is run substantially increases understanding and retention (Caulton, 1998).

Interaction within the museum is particularly important given why people visit museums. While many different social groups visit museums, the majority of visitors are families and this has been the focus of considerable research. Children want to manipulate the exhibits while adults are more likely to read posted information. When families go to a museum however, each individual's interaction with the exhibits changes. One study showed that museum goers will not read instructions before interacting with an exhibit. They will not even look to the instructions if they are confused without first attempting to solve their confusion by working out the problem themselves (Falk and Dierking, 2002). This illustrates two points. First, children crave interaction. Children are not content to simply read about an exhibit, they want to jump right in and explore material in their own way. Secondly adults use the interactive nature of museum exhibits to interact with the members of their family. Indeed Falk and Dierking have compiled studies which found that most families go to museums as an excuse to spend time together as much as to learn something new (Falk and Dierking, 2002). Interactive museum exhibits allow children to actively engage the material and parents to interact with their children, creating a positive museum experience for everyone.

The shift towards interactive learning began with Jean Piaget, one of the early leaders in interactive teaching (Caulton, 1998). His work in the 1920s claimed that young children especially need to experience the world hands-on and that traditional lectures are not very effective at teaching them. He hypothesized that children see the world differently than adults and need to be taught as such. This would not become widely adopted in the formal sectors, like classrooms, or informal education sectors, like museums, until the 1950s.

In contrast to Piaget, some critics like British psychologist Richard Gregory worry that, “although hand-on experience is effective, indeed essential for learning, to see objects, hands-on experience can hardly be accurate for aiming at scientific understanding,” and wonder, “Are they [children] really learning or are they merely playing,” (Caulton, 17). Gregory worries that museums have gone from a place of education to a playground. While Gregory is not alone in his concern and these concerns are not without merit, other literature refutes his claim. It instead provides support for the idea that more traditional structured lectures supplemented by interactive teaching techniques, such as science class supplemented by afterschool clubs, work well to both stimulate interest in subject matter and increase material understanding.

Crouch (2004) studied the impact of adding interactive elements to a classroom demonstration. She tested four groups of students who were presented with the same information in four different ways: (1) in a traditional lecture; (2) in a non-interactive demonstration; (3) in a demonstration with time for students to make predictions about the outcome of the experiment; and, (4) in a demonstration, with time for predictions and a discussion with their peers about how to evaluate the results. Crouch found that while a non-interactive demonstration yielded no addition knowledge retention over a lecture there was a significant increase in both the ability to determine the outcome of a similar experiment as well as the reasons behind that outcome in the prediction and discussion groups. The discussion group in particular had a particularly high retention rate of the outcomes and a better ability to explain the underlying principles. This improved response from interaction between students further enforces the idea that interactive learning techniques are even more effective when used in an appropriate social context (Falk and Dierking, 2002). The statistical results of the experiment shown in Table 2 (Crouch, 2004, 836) illustrate in the $R_{outcome}$ column the percentage of correct responses given for a method, while the R_{expln} column shows the percentage of students capable of adequately explaining the foundations behind the demonstration. This study concluded that greater student interaction results in higher retention rates in both cases.

		Outcomes			Explanations			
Mode	N	$R_{outcome}$	$p_{outcome}$	$h_{outcome}$	R_{expln}	p_{expln}	h_{expln}	Time (min)
no demo	297	61%	⋯	⋯	22%	⋯	⋯	0
observe	220	70%	0.03	0.19	24%	0.64	0.05	11
predict	179	77%	<0.001	0.35	30%	0.04	0.18	13
discuss	158	82%	<0.0001	0.47	32%	0.02	0.23	21

Table 2: Effectiveness of learning techniques

This seems to refute the claim that interactive learning merely increases students' enjoyment of the material, but not their comprehension (Crouch, 2004). While some critics of this study may claim that the additional time afforded to the more interactive groups accounts for their increase in knowledge retention this is largely countered by the fact that the demonstration and not the prediction or discussion periods accounted for most of the extra time. Furthermore it also shows that a non-interactive demonstration does very little to help students learn which emphasizes further the importance of interactive education. Students learn more when they are exploring the material themselves, asking their own questions, and coming to their own conclusions rather than just being told the information and what to think of it.

Given that interactive learning approaches are proving necessary to an optimal educational experience, questions arise about how to construct interactive experiences properly, especially with class time at a premium. As previously stated Shmaefsky explains that students remember science demonstrations, when performed well, for years making them useful supplements to traditional lectures. However he cautions that the “fun” in an interactive demonstration should be in watching principles in action, that way scientific lessons are reinforced rather than just seeming boring in comparison to the activity. Expanding on this thought he suggests that demonstration should be used to reinforce what has already been taught rather than introduce new material. He cautions that attempting to introduce entirely new material through interactive demonstration such as a laboratory exercise will only result in confusion and misconception. He pushes the idea of putting students in an inquiring mindset while reminding them of the scientific principle they are exploring. One should always tie an activity back to the concept its teaching in a way that is obvious to students (Shmaefsky, 2009). While Shmaefsky’s ideas on interactive learning and its use in education mostly relate to a classroom context, his ideas also apply to a museum environment.

2.3 Museum Outreach Techniques

Museums are often looking for ways to stay relevant and connected in a changing society and have increasingly emphasized educational outreach to supplement and assist the formal education sector. As Barragree notes, “Museums and educators have used curriculum materials based on museum content to enrich the education of students and to ensure that learning objectives have been met. These partnerships have the ability to make almost any subject more relevant to students' lives, increase students' interests, and make learning more effective” (Barragree, 2007). This section describes the various approaches museums use to reach out to schools and formal learning establishments in order to enhance the educational experience of students. These approaches include museum visits and exhibits, special events and programs for students, programs provided both inside and outside the museum, websites, and resources for teachers.

2.3.1 Visits to Museums

Visits to museums provide educational experiences for children in an informal setting and are often used to supplement a student’s curriculum. According to Falk and Dierking, “A significant percentage of nearly every museum’s visitors are children on school field trips” (Falk and Dierking, 2002). In an English study, Hooper-Greenhill (2004) found 38% of teachers believed that museums were important while 58% believed they were very important. Educators use museums to enhance their pupils’ learning because it offers an enjoyable and interesting way to understand topics. Although most teachers find museums to be beneficial, some teachers believe they are not worth the trouble and do not have much to offer their students. For example, Alexander found that many teachers do not have a desire to work with museum staff or educators and are unsure of the value of museum experiences (Alexander, 1980). This supports similar findings by Hooper-Greenhill (2004).

This reticence on the part of teachers may merely indicate that teachers are not well informed about what museums can offer and the positive outcomes that flow from a museum visit. Hein, a well-respected expert on museum learning, claims that "one of the marvels of museums is that the brief encounters visitors have with exhibitions do appear to lead to learning, do result in some change in the visitor that is often remembered with pleasure and can influence future behavior" (Hein, 1998). He later advises that "'minds-on' as well as 'hands-on'" activities are necessary in a museum education (Hein, 1998).

Museums not only provide opportunities for students to come and explore exhibits but also special events and programs to take part in at the institution. Barragree asserts that "Museum experiences must be more than field trips or a reward at the end of the year" (Barragree, 2007). Many museums have also realized this and implemented other opportunities for students. These come in the form of summer courses, camps and vacation week programs, lectures, competitions, and even overnight stays. For example, the Worcester Art Museum offers art classes and lectures for students and holds the Art All-State program where high school juniors come from all over Massachusetts to examine art and partake in a collaborative project (Worcester Art Museum, 2009).

2.3.2 Outside the Museums

While visiting provides a great educational experience, museums attempt to educate children by taking their resources into the community. This can be done through visits by museum educators or kits and activities that can be sent to schools. For example, the Boston Museum of Science provides special programs that are held throughout the Boston area to interest children in specific subjects and reach out to those who may not be able to conveniently visit the museum (Museum of Science, 2009). The New York Hall of Science has lab kits that can be rented by teachers along with lesson plans and other activities that can be borrowed through their Science Technology Library (NY Hall of Science).

Another way museums try to reach students outside of the building is through the internet. The continual advance in technology has presented museums with this new way of communicating knowledge and, taking advantage of this opportunity; many museums have invested in websites to enhance their educational outreach. Sumption notes, “The internet has captivated many museums and particularly their educators. As a communication medium, the Internet allows museum educators to enter the homes and schools of students without their ever needing to visit the museum (Sumption, 2001).” While websites cannot replace the experience of a visit, they do serve as an additional resource for those wanting to discover what the museum has to offer and also to reinforce learning after a visit.

Museum websites also offer multiple ways for students to learn. Many websites contain activities called Electronic Field Trips which allow students to explore worlds they may never see in real life. These “field trips” include tropical rainforests and historical periods (Sumption, 2001). Students are allowed to explore parts of the museum through virtual exhibits as at the Museum of Science in Boston (Museum of Science, 2009). Some museum websites also have Expository Teaching Resources which lead students through activities that present a set of principles. (Sumption, 2001) The students learn concepts related to their school curriculum while having fun and accomplishing the tasks.

2.3.3 Teacher Resources

Many museum efforts focus on students but teachers may also benefit from their offerings, which include curriculum information, lesson plans and activities, workshops, and courses. During visits, museums offer information to educators on how specific exhibits or activities relate to their curriculum. Information is presented on extension activities and labs too. At the New York Hall of Science, each exhibition contains “Educator Guides” that are available for teachers which include information on curriculum connections, national standards, continuum guidelines and activities, and related books (NY Hall of Science, 2009).

While curriculum information and activities are presented by the museum, workshops and courses appear to be the main outreach offered to teachers. These programs serve to educate teachers in a variety of areas, such as teaching methods and special topics or subjects, in an effort to enhance their performance in the classroom. The MIT Museum takes part in the Museum Institute for Teaching Science (MITS) program each summer allowing teachers to learn how to make science more accessible to their students (Brown, 2006). In 2003, the John F. Kennedy Library and Museum held a five-day course to teach educators about the Civil Rights Struggle.

Its purpose was to “enhance their understanding of this crucial time in the nation’s past so they may better teach students about it in the classroom” (Civil Rights, 2003).

2.3.4 London Science Museum Outreach Efforts

The Science Museum in London has worked to incorporate many of the outreach techniques described previously in an effort to supplement the formal learning of children. They have enhanced the experience of visits by adding and enriching their exhibits for children. This is evident through the newly developed Launchpad gallery which contains over 50 interactive exhibits, along with shows and demonstrations, relating to physics topics such as light, energy transfer, force, and magnetism (Science Museum, 2009). The Science Museum has also developed exciting shows and presentations, such as educational movies shown in their IMAX 3D cinema and presentations such as *The Supercool Show* which explains energy transfer and changes of state through exciting and interesting demonstrations (Science Museum, 2009).

The Science Museum offers many educational tools for students outside of the museum. Staff members run many shows and workshops in schools. For example, *Danger High Voltage* is a 45 minute presentation for up to 300 students that includes high voltage demonstrations on electricity and magnetism (Science Museum, 2009). The museum has created a website that allows students to explore parts of the museum and also allows students to search for information related to topics covered by the museum’s exhibits. As a way to interest students further, the Science Museum’s website contains games and interactive activities. One game is called *Energy Flows* in which children have to figure out how energy flows from the source, such as the sun, to the product, such as music (Science Museum, 2009).

The Science Museum also reaches out directly to teachers. They provide professional courses, administered by the museum’s experienced Learning Team, which educate teachers on new techniques to incorporate in the classroom and how to get the most out of what the museum has to offer. One popular course is *Talk Science* which aims to inform teachers how to run classroom discussions on science issues (Science Museum, 2009). The Science Museum also offers programs for teachers that can be brought to schools, training for new teachers, and film and gallery previews which allow teachers to decide which are applicable to their students. Lastly it provides classroom and homework resources that teachers can adapt to supplement their curriculum. Many of these are hands-on activities that stimulate interest and enjoyment in the subjects being studied.

In addition to the techniques outlined above, the Science Museum has begun development of science activity boxes to be used in STEM clubs. Their purpose is to supply teachers with a resource they can easily use and run in their clubs as well as excite and interest the students. The ability of STEM clubs to use these boxes will greatly enhance the students experience allowing for not only museums to play an important role in a student's education but STEM clubs as well.

2.4 STEM Clubs

Afterschool clubs supplement traditional lecturing with informal, hands-on activities. As a part of their efforts to increase the number of students choosing to take STEM subjects, the British government provided £5 million in funding for 250 afterschool clubs in 2007 (STEM Support Centres, 2007, 3). These clubs were intended to cater to students in Key Stage 3 in order to capture their interest in science and engineering so they could take more advanced STEM classes in preparation for college (Science and Innovation Investment Framework, 2006, 11). Due to the informal, afterschool setting of the clubs, maintaining student interest is key to a club's success. The club should not have written assignments or act as a review session for tests or exams (Science and Engineering Club Handbook, 2008, 6). While the organization and activities vary from club to club, the more successful ones tend to have several key similarities.

2.4.1 Club Evaluation

In 2008, an evaluation of these science clubs was conducted to investigate what function they served in the schools and their effectiveness (Mannion and Coldwell, 2008, 1). The report addressed the nature of typical club activities and the impact on the students, and made several recommendations for improvement. Many of the clubs looked for recruits among those gifted and talented in STEM subjects (Mannion and Coldwell, 2008, p. 20). This could impact the club's makeup in several areas. It may increase the number of motivated and skilled members, but it could also intimidate less gifted students and leave them out.

Regarding the impact on the students' learning, the report concluded, "The vast majority of club leaders and other staff saw improvements in practical skills, self-confidence and thinking skills of pupils" (Mannion and Coldwell, 2008 p. 33). In addition, the students themselves became more interested in pursuing higher level courses and careers in STEM. Some areas for improvement include more activities based on math and engineering as well as more opportunities for creativity and independent work. However, all in all, this study concluded that the STEM clubs were achieving their intended goal (Mannion and Coldwell, 2008 p. 49).

The UK is not the only country to implement afterschool clubs as a means to increase interest in technical fields. For example, Professor Terri Rhoads studied several clubs formed at local elementary schools in Oklahoma (Rhoads, 2006). Like clubs in the UK, these clubs focus on experiments and activities in an informal setting in order to “interest or maintain interest of elementary children by making science and engineering come alive” (Rhoads, 2006, p. 6). While this was not a longitudinal study, Rhoads found that the students enjoyed the activities and became more interested in STEM (Rhoads, 2006, p. 10).

A study conducted in Massachusetts in the mid 1990s found that students became more interested in STEM subjects after a hands-on summer camp experience (Gibson & Chase, 2002, 703). The study involved a survey and interviews with students attended a summer camp designed to increase interest among middle school students in STEM careers. Through the use of a longitudinal survey, the researchers were able to measure the interest level of the students over a period of a few years. They also had two control groups, one group who applied to the camp, but did not get in, and another group selected from the schools these students attended that did not apply to the camp. The study found that all groups experienced an average decline in interest in STEM careers from middle school to high school but the decline among those that attended the camp was less dramatic than in the other two groups (Gibson & Chase, 2002, p. 703). Qualitative data about the effectiveness of the summer camp was gathered through interviews with students who attended the camp. Common themes in the interviews include enjoyment of the interactive activities at the camp and a general expression of interest in science. However, when asked if they liked taking STEM subjects in school, many expressed frustration and boredom with structured note-taking and lectures (Gibson & Chase, 2002, p. 702). Although the reasons for the plunge in interest after middle school were not investigated, it is clear that hands-on activities and informal learning settings can prevent it.

2.4.2 Club Activities

One of the most difficult tasks for the UK club leaders to complete is the planning of hands-on activities for their clubs to engage in. Although each club is free to choose its own activities, many teachers would appreciate outlines for activities to start from (Mannion and Coldwell, 2008, 28). Several organizations exist to assist clubs in both activity-planning and networking. One of these, STEMNET, is a government organization that was founded to enrich the STEM curriculum and build interest among students for science and engineering subjects (STEMNET, 2008). With regard to afterschool clubs, STEMNET has links to other organizations involved with STEM including the British Science Association, the Young Engineers, as well as the London Engineering Project. All of these organizations have developed activity plans that club leaders can follow, but they leave gathering materials up to the teacher.

The plan that the Young Engineers have developed is particularly helpful. It provides detailed instructions, lists material requirements, and explains how each activity links to the curriculum (Intermediate Level Examples, 2006). Most of these activities include a competition among the participants to see who can build the lightest bridge, highest tower, and so forth. These resources prove a powerful tool, though it is unclear how many teachers are aware of them (Mannion and Coldwell, 2008, 29). The availability of resources has a large impact on the activities STEM clubs engage in. Figure 3 shows the most popular types of activities involve energy, rockets, racing cars and robotics. Unfortunately, many of the more popular activities tend to appeal more to boys, and the least popular, such as cosmetics and lighting and color, tend to appeal more to girls (Mannion and Coldwell, 2008, 30). This may also reflect gender bias in population of students that participate in these clubs. One goal of the STEM clubs is to increase cooperation between schools and between higher education institutions and industry. Figure 4 shows that the clubs are actively pursuing this goal, since 10% of clubs visited a local business and 22% visited a university. More notable, is the important role that museums play, since fully 40% of clubs indicated that they visited a museum. There seems to be room for a stronger partnership between clubs and museums.

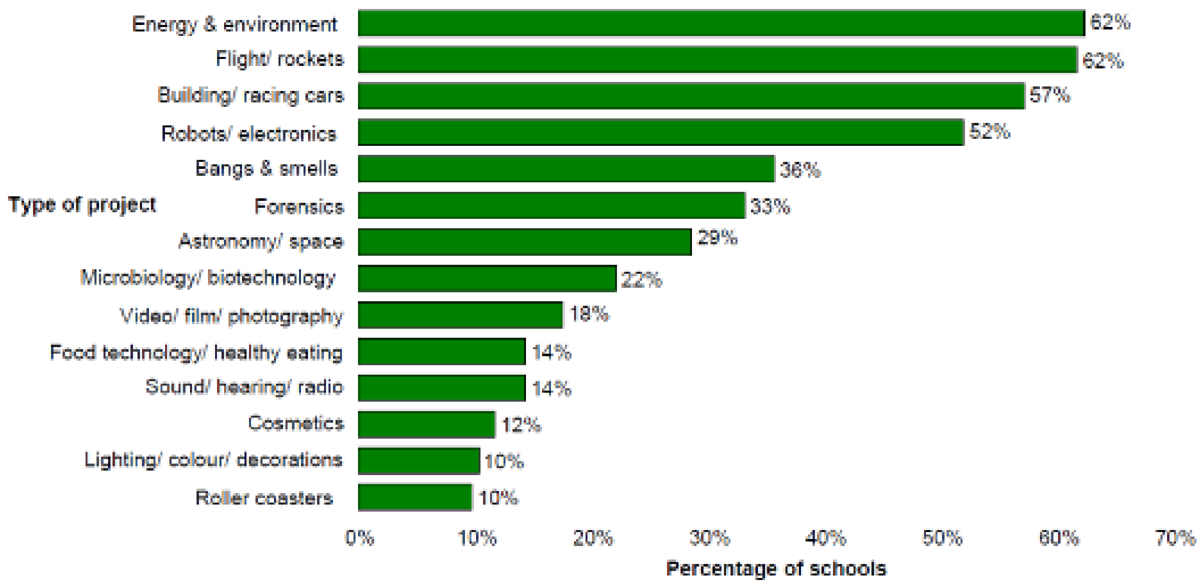

Figure 3: Percentage of different STEM club activities

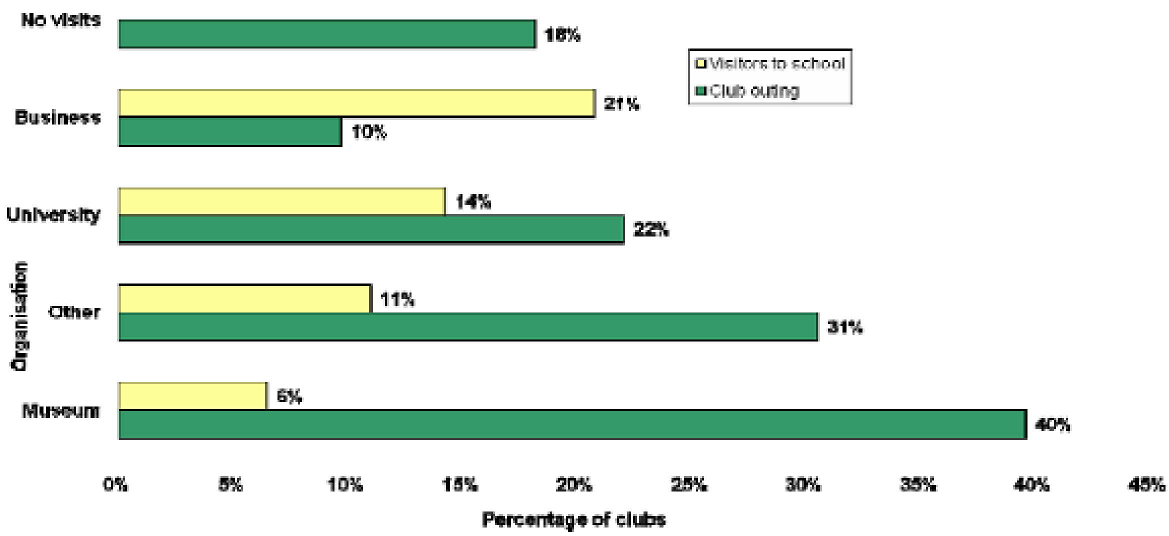

Figure 4: Graph of outreach to STEM clubs

2.5 Science Boxes Background

The Science Museum has been developing science club boxes to provide more resources for the teachers leading the STEM clubs. This project has been in development since September 2008 and will launch in September 2009. Anna Phlippen, Learning Resource Officer, is the lead on this project and our liaison at the Museum. These boxes have several aims. For the students, the focus of these boxes is to provide fun activities that will excite them about science. The boxes contain all the materials that a teacher needs to run an engaging, educationally- and age-appropriate science activity, including detailed instructions and supporting resources. The ideal box would make preparing for the activity quick and straightforward and be flexible in terms of time constraints and delivery. All in all, these boxes should help the teachers and include what they need to run the activities.

The Science Museum is currently developing and testing the Crime Lab and Mars Mission boxes. Figure 5 shows a breakdown of the activities included in each box, with those selected for our evaluation highlighted. Each box contains all the more 'exotic' materials necessary to complete these activities (less exotic materials, such as pencils, paper, tape, etc. are assumed to be available in the classroom). The materials included with each activity can be seen in Table 3. The boxes also include several different resources for the teacher running the activity. A list of the resources and their intended purposes can be found in Table 4.

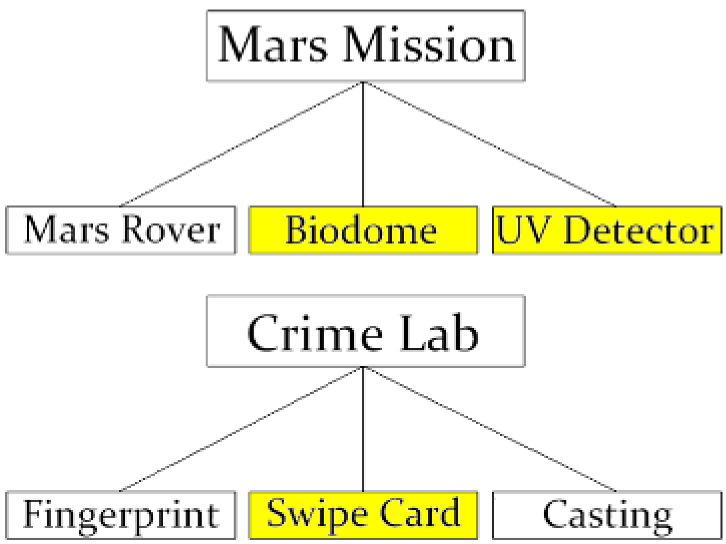

Figure 5: Activities included in boxes

Activity	Box	Special Materials
Swipe Card	Crime Lab	Swipe cards, metal powder, brushes, magnets
Biodome	Mars Mission	Plastic biodome, phase change powder, nutrient crystals, seeds, Petri dishes, and thermometers
UV Detector	Mars Mission	UV-sensitive hand, sunscreen, UV LED lights, batteries

Table 3: Activity materials

Resource	Purpose
Teacher Notes	Includes instructions for running the activity, links to the curriculum, and links to real life
PowerPoint	Used during activity to lead students through activity. Has pictures of how to do the activity
Poster	Advertisement for the club
Film	Introduces the activities in the box
Logbook	Place for students to write notes and tape things in. Includes pictures and facts about box.

Table 4: Teacher resources

The museum has identified three activities that this project will evaluate and improve. These activities include the Swipe Card activity from the Crime Lab box and the Biodome and UV Detector activities from the Mars Mission box. These activities are still in the prototype phase and have not been tested before, but some ideas have been suggested by teachers in two focus groups. One major outcome of these focus groups has been the inclusion of a student logbook, which was an idea teachers came up with. Other changes and requests for resources have also been recommended.

2.5.1 Science Box Activities

The Crime Lab box as a whole focuses on identifying the perpetrator of a fictional robbery from the Science Museum. The introductory film is a news show with CCTV (closed-circuit television) footage of a man trying to break into an exhibit and steal George Washington's wooden teeth. The newscaster in the film describes some key evidence and then encourages the students to solve the crime. The robber forged a security swipe card to get into the exhibit, but left it behind at the crime scene. The card contains information about when he entered the exhibit in a code on the magnetic strip of the card. The actual activity involves students brushing metal powder onto the magnetic strip and using sticky tape to transfer the code onto a sheet of paper. Figure 6 below shows two students brushing the metal powder onto the card. Using a decoding key, the students can determine the time the card was used and compare it to a list of suspect alibis to identify the robber.

Figure 6: Students doing Swipe Card activity

The Mars Mission box focuses on a future Mars mission and what the astronauts need to consider for survival. The introductory film shows a movie director pitching her science fiction film of a mission to Mars and lists the hazards that future astronauts will face. One important factor is that they will need to grow their own food and provide the plants with an Earth-like environment to grow in. This is the basis behind the Biodome activity. A plastic biodome structure is constructed by the teacher and students investigate the effects of a mysterious “phase change material” on the temperature of the dome. This material is intended to absorb heat during the day and release it at night to keep the biodome warm. Figure 7 below shows students measuring the temperature of the phase change material under the biodome. Since the temperature varies widely on Mars from night to day, this could help astronauts survive. Students will also use hydroponic growing methods to grow plants under the dome. A special kind of nutrient crystals and seeds are included in the box for this activity.

Figure 7: Students doing Biodome activity

Another important factor to take into consideration for a future Mars mission is the dangerously high levels of ultraviolet (UV) radiation on Mars. Any astronauts will have to be shielded from this radiation in order to survive. Materials for this activity include a hand shaped gel that changes color with increasing amounts of UV exposure and a UV light. Students can see the effects of UV rays on the hand and experiment with different materials, such as sunscreen, clothing, and aluminum foil. Figure 8 shows students experimenting with the hand and sunscreen. Determining how well each material shields the UV –sensitive hand from UV radiation is an important goal of this activity.

Figure 8: Students doing UV Detector activity

3. Methodology

The goal of this project was to improve the Science Museum's teacher resources by finding teacher and student opinions of the science boxes. We achieved this through a series of tasks. The four main tasks for this project were to:

1. Develop a protocol to evaluate the Science Museum science boxes;
2. Use the protocol to evaluate selected activities from the boxes at a sample of schools;
3. Recommend how to improve the boxes based on the findings of the evaluation; and,
4. Implement selected improvements to the boxes, develop new extension activities accordingly, and conduct preliminary assessments of their effectiveness.

The following sections describe the implementation of these objectives.

3.1 Evaluation Protocol Development

The evaluation protocol was honed through an extensive process of testing and refinement. The project team developed a preliminary evaluation protocol based on a thorough review of the literature, and conducted a preliminary pre-test of the protocol at the Thomas Prince School in Massachusetts. The protocol was revised and presented to staff at the Science Museum. Based on the feedback received, the team chose to move towards a more qualitative and open evaluation which resulted in significant changes to our methods. Through further collaboration with our liaisons, we finalized our protocol and implemented it at six science clubs.

The original protocol included an observation worksheet, student surveys, and teacher surveys. Much of the observation worksheet was structured and based on several questions with Likert scales rating categories such as student engagement, teacher's ability to administer the activity, and how much the students enjoyed the activity. The student surveys included both a short interview as well as pre- and post-activity questionnaires to test information retention and changes in STEM interest. The teacher survey included an interview as well as a follow-up questionnaire to be mailed back later. These initial protocol worksheets can be found in Appendix A: Initial Protocol Worksheets

The group performed a pretest with these preliminary evaluation techniques on March 9, 2009 at Thomas Prince School in Princeton, Massachusetts. The group took instructions and materials for a science activity to a classroom of 10 and 11 year old students. Due to communication problems, the teacher was not prepared to conduct the activity and two of the group members had to administer it. While the two members facilitated the activity, one group member utilized the preliminary protocol.

The purpose of the pretest was to identify any potential flaws with the observational protocol, interviews, and surveys. We found that the observational worksheet was too structured. It needed to be more open-ended with a section for notes. It was apparent from this pretest that some questions needed to be changed due to confusing wording. The survey questions were also confusing for some children which necessitated the rewording of them as well. The last problem the group noticed from the pretest was the amount of time the students took to complete the questionnaires.

These problems were addressed by the group and presented to our liaison at the Science Museum. Our liaison had developed a set of aims for the boxes that were collected into a model of success for the boxes. This document can be found in Appendix B: Model of Success for Boxes. The model was simplified into a list of objectives for the evaluation. The objectives of the evaluation are to determine:

- What students and teachers think about the introductory films.
- What students and teachers think about the student logbooks.
- How well the Swipe Card, UV Detector and Biodome activities function in a club setting.
- The teacher’s opinion of the support materials for each activity including the PowerPoint, poster and teacher notes.

Through a collaborative effort, we filled in the gaps that our evaluation protocol did not cover by modifying our interview questions. Building on our liaison’s prior experience evaluating STEM clubs, we decided to have three group members each interview two students at each session rather than have all the students at each session fill out lengthy questionnaires.

The group also attended a seminar with the Science Museum’s Audience Research Team, whose mission is to evaluate museum programs and exhibits. The improvements suggested in this seminar included a major revision of the observation worksheet. We changed the worksheet from a quantitative scale towards a qualitative approach with open ended responses. We also reworded the student and teacher interviews. The final protocol consisted of an open-ended observation sheet as well as two lists of interview questions for the teacher and students. The observation sheet can be found in Appendix C: Observation Protocol. The teacher interview worksheet can be found in Appendix D: Teacher Interview Questions. The student interview worksheet can be found in Appendix E: Student Interview Questions.

3.2 Implementing the Activity Evaluation

Prior to the team's arrival in London, the Science Museum identified six STEM clubs where the activity evaluations would be conducted. These clubs were chosen to obtain a diverse sample of schools. They encompass a wide range of geographical and socioeconomic areas and include four mixed gender and two all-girls schools. Table 5 provides basic information about the schools selected, including location, activity evaluated, and whether the STEM club meets during or afterschool. Before each evaluation exercise, the Museum sent the prototype science box (including the film, materials needed to conduct the activity, student log books, and teacher instructions) to the teacher leading the club session. Several days before the visit, our liaison cleared with the teacher that the group would be conducting interviews and secured the permissions necessary to interview selected students from the class.

School	Activity	Location	Gender	Meeting Time
Southgate	Swipe Card	London	Mixed	Afterschool
Tom Hood	Swipe Card	London	Mixed	Lunch
Bramhall	Biodome	Manchester	Mixed	Lunch
Maidstone	Biodome	Maidstone	Girls	Lunch
St. Angela's	UV Detector	London	Girls	Afterschool
Parmiter's	UV Detector	Watford	Mixed	Lunch

Table 5: Schools visited information

3.2.1 Activity Observation

The first part of each club visit was an observation of the club members participated in the selected activity. The members of the research team stood off to the side or in the back to avoid interfering with the activity. Depending on the number of students and how they split into groups, the project members split up in order to closely observe as many groups as possible. We also observed the teacher introducing the activity and any interaction he/she had with our selected group as can be seen in Figure 9. By conducting a close observation, we overheard student conversations and their reactions to different parts of the activity. A major part of the observation was seeing whether or not the activity worked as intended. Any problems the teacher or students encountered were noted.

Figure 9: Teacher and students in club observation

Since each group member completed separate observation worksheets, we compiled composite results in a spreadsheet (see Appendix F: Data Analysis Spreadsheet Example). We broke up the observations into whether they were observations of the teacher or of the students. After this, the data was grouped according to what aim of the box it addressed. For example, an observation that the students could not do a certain part of the activity was entered under the "Students can complete the activity" aim. Each group member had a space under each aim for their data so that it was easy to see any trends that were seen by multiple observers. In addition, the observations were coded by color to indicate whether they supported, opposed, or were neutral to the aim. Through this coding method, the data of multiple observers could be analyzed much more easily.

3.2.2 Teacher Interviews

After the completion of the activity, one member of the project group would interview the teacher who ran the activity as can be seen in Figure 10. This interview was fairly structured with a list of questions to run through in order. Probe questions and rephrases were included in case the teacher did not answer the question sufficiently. Permission to interview and use quotations was taken care of in advance by our liaison. The interview focused on the teaching resources included in the box and how the teacher used them. We also included questions on whether they liked the activity for their students as well as how easy it was to run the activity. In the even there was insufficient time to complete the interview; any unanswered questions were answered via email.

Figure 10: Group member interviewing a teacher

The coding of the data from the teacher interviews was very similar to that used for the observation data. In this case, there was only one source of data so compiling different group members' findings was not necessary. We again used a spreadsheet to organize this data according to the aims of the boxes. In this case, we listed the questions from the interview in rows and coded the response by what aim they addressed. If necessary, the teacher's answer was broken into pieces if it addressed multiple aims. Again the data was coded based on whether or not it fulfilled the aim it fell under.

3.2.3 Student Interviews

While one group member interviewed the teacher, the other three would conduct student interviews. Time constraints made it difficult to conduct separate interviews so each group member interviewed two students simultaneously as can be seen in Figure 11. These students were selected by the teacher beforehand. A diverse sample was desirable in terms of aptitude, interest in science, and gender. We made sure that we also had one student from each group. These interviews were structured similarly to the teacher interviews with options for probes and rephrasing if the student did not understand the question. The focus of the questions was on whether the students liked each part of the activity. These parts include the activity itself, the film, the logbook, and the links to real life.

Figure 11: Group member interviewing two students

The student interviews were coded in the same manner as the teacher interviews. All of the questions were listed in the rows and the aims of the boxes were listed across the columns. Since there were three group members with two student interviews, we had room for each group member's data under each aim. To differentiate between students, their responses were separated by slash marks in each cell. Once again, the data was coded based on whether it fulfilled the aim it was listed under or not.

3.3 Data Analysis Process

Once all the data we collected was compiled into spreadsheets, we needed to further organize it and begin data analysis. Although there had been some variation between how each group member coded his or her data, we discussed what each aim meant to ensure consistency. Any further ambiguities were discussed or placed in the "other" category we created in the spreadsheet. For each school, the spreadsheets for the observations and interviews were combined into a file with multiple sheets. Since each activity was done at two schools, it was necessary to look through the spreadsheets for both schools for trends. Due to our color coding method, it was easy to get a first impression of how well the activity achieved a certain aim by comparing the amount of green or red in the data below it. After this initial reading, we compared the findings from each group member to see if a common trend arose. If this trend was found, we looked for specific observations or interview questions that addressed our initial reaction. Another important consideration was whether our observations were corroborated in the interviews. For example, if we observed that students seemed to like the links to real life, we would see if they said so in the interview. By triangulating between our different evaluation techniques, we could draw much stronger conclusions.

3.4 Implementation of Selected Recommendations

Once the data we collected was analyzed and our recommendations presented to our liaison, we selected those we wished to implement. These implementations were selected based on their priority as well as the time needed to finish them. With only a short time available after the recommendations were presented, there simply was not enough time to fix everything. Since we found significant problems with the materials and instructions for each activity, we elected to fix those first. These were broken up into individual tasks. Additionally, the group developed a new activity for the museums' website and designed four new extension activities for the boxes.

A group of museum staff attended a focus group where we presented and tested our ideas. The staff members encompassed a wide range of disciplines and were asked to provide feedback on our improvements. For this focus group, we developed a list of what we wanted to address and some questions to lead a discussion after each activity. We designed worksheets very similar to those we used to evaluate the activities. The feedback from this focus group was taken into consideration and any necessary changes were made to our recommended improvements and new activities.

4. Data and Analysis

Data was collected from the club visits as described in the previous chapter. There were three sources of data: observations, teacher interviews, and student interviews. This chapter presents an analysis of the data as well as recommendations for improvements to the activities. Following a brief description of the sample, the findings are presented in the following order: activity content, teacher resources, introductory films, and student logbook.

4.1 Sample Characteristics

We observed the implementation of three activities (Swipe Card, Biodome, and UV Detector) at six schools. Each activity was run at two schools (Table 5). Some clubs met for twenty or thirty minutes over lunch while others met for longer afterschool (Table 6). A total of 64 students were observed at the six schools; 39 of them were interviewed (Table 7). Each of the six teachers that ran one of the club sessions was interviewed as well.

School	Date	Activity	Meeting Time	Session Length	Logbook Distributed?	Film Shown?
Southgate	3/23/2009	Swipe Card	Afterschool	45 min	Yes	Yes
Bramhall	3/26/2009	Biodome	Lunch	30 min	Yes	No
Maidstone	3/27/2009	Biodome	Lunch	35 min	No	Yes
St. Angela's	3/30/2009	UV	Afterschool	50 min	Yes	No
Parmiter's	3/31/2009	UV	Lunch	30 min	Yes	Yes
Tom Hood	4/1/2009	Swipe Card	Lunch	25 min	No	Yes

Table 6: School visit times and film/logbook usage

School	Number of Boys	Number of Girls	Number of Students Interviewed	Teacher Gender
Southgate	5	1	6	Male
Bramhall	7	3	6	Male
Maidstone	0	7	7	Female
St. Angela's	0	12	6	Female
Parmiter's	8	7	6	Male
Tom Hood	10	4	8	Female

Table 7: Club demographics

We encountered several deviations from our protocol. At Maidstone and Parmiter’s, more students were interviewed than at other schools because the teacher sent too many students to the interviews and we lacked a protocol for rejecting them. Since the students at Maidstone and

Tom Hood did not receive the logbook to use during the session, we asked the students to examine and comment on copies provided during the interview. Bramhall and St. Angela's did not show the film so the students could not give their opinions about the film. All the teachers had viewed the film before and/or during the session and were asked to give their opinions.

4.2 Activity Content

Generally speaking, teachers and students liked the content of all three activities. Students enjoyed the activities and how they linked to their daily lives. Teachers liked tying these activities to the curriculum and teaching their students practical science skills. Nevertheless, teachers and students identified several major and minor problems with each of the activities related to faulty materials or unclear directions.

4.2.1 Biodome

Bramhall and Maidstone schools tested the Biodome activity. The session at Bramhall met over lunch and lasted 30 minutes. Seven boys and three girls attended this session and broke up into two groups. Six students were interviewed. The logbook was used, but the teacher chose not to show the film since he did not think it complemented the activity. Instead, he made up his own PowerPoint presentation to introduce the activity. The Maidstone club also met at lunch for 35 minutes. Seven girls in the club broke up into three groups. Logbooks were not distributed at this school since the teacher did not receive them. The film was shown as expected.

Maidstone is an all-girls school and the students were uncomfortable around the male observers. This presented problems in the student interviews. Consequently, the two male group members interviewed the teacher while the other two female members interviewed students. Due to the confusion from this, all seven girls in the club were interviewed.

Students at both schools liked the context for the activity (i.e. survival on Mars). They appeared engaged and were generally on-task throughout the sessions. Students were eager to answer their teacher's questions in discussion and asked some of their own about the activity. Students at Bramhall were particularly enthusiastic to respond to questions that focused on the survival of astronauts on Mars and differences between the environments of Mars and Earth. These students were excited to be able to link the Biodome activity to the Eden Project. The Eden project is a set of large-scale biodomes in St. Blazey, UK that opened in March, 2001. It features the largest greenhouse in the world as well as two biodomes that simulate rainforest and Mediterranean climates (Eden Project).

Students at both schools seemed very excited when mixing the nutrient gel with water and then ‘planting’ the seeds. At Maidstone, the teacher turned the activity into a competition to see who could produce the best plants. Students enjoyed this and vied for the best mixture of gel and the best spot under the biodome. Students from both schools said that their favorite part of the activity was mixing the gel crystals with water and the seeds. Figure 12 below shows that the majority of students (11/13) enjoyed the activity, and no one rated the activity unfavorably. All of the Bramhall students thought positively of the activity and most were interested in what else they might do with the gel. A few students stated that they enjoyed measuring the temperature of the biodome with the phase change material. At Maidstone, students liked the new materials and trying to find the appropriate mixture of nutrients and water for the plants. Overall the students at both schools enjoyed the Biodome activity.

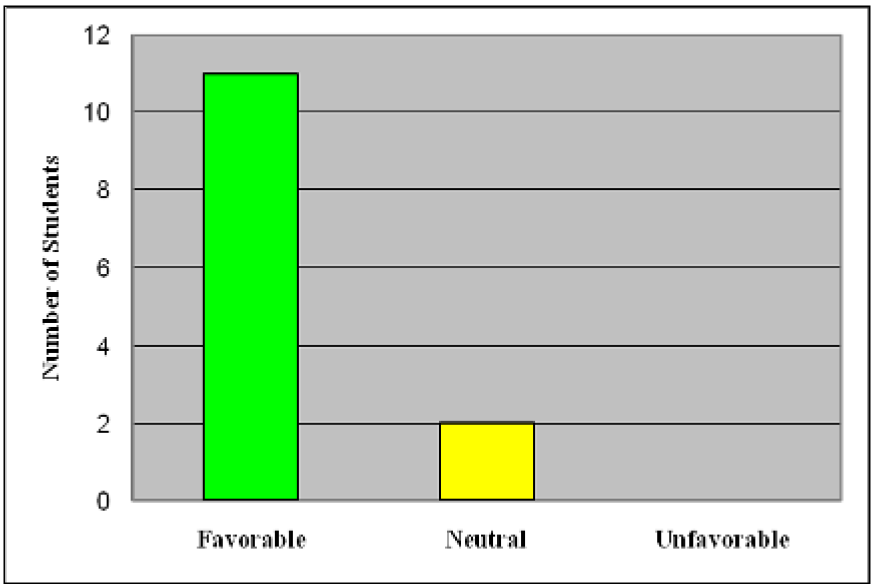

Figure 12: Student opinion of the Biodome activity

Both teachers indicated that they liked the STEM content in the Biodome activity and its links to the curriculum. The teacher at Bramhall thought the STEM content was “brilliant” and that there were “loads” of links to the curriculum. He was delighted that he was able to connect it to a previous club activity involving acid reactions. The teacher really felt that he could work in more science during their discussion of the activity. At Maidstone, the teacher said she had related the activity to their space and solar system unit, although there were few links to what her students were covering that year. She also stated that she was able to use the activity to teach investigative skills to her students. The two teachers' responses to the Biodome activity make clear that it has sufficient links to the curriculum.

Although both teachers liked the content of the activity, the materials were too difficult to use. The Bramhall teacher said that assembling the biodome was a "nightmare." The Maidstone teacher agreed that it took too long to assemble the biodome. The phase change material failed to function as expected in both sessions. Students could not measure any significant difference in its temperature over the course of the club session. Both teachers were unsure of how to use the phase change material and asked us how much to use and how it was supposed to work. The seeds did not and cannot grow during a single session, leaving little to be accomplished during one meeting of the club. Only the crystals performed as expected in one session.

Critical flaws with this activity include the lack of a short term activity as well as unclear directions. Recommendations to correct these flaws are listed as follows:

- The phase change material needs to be replaced with a material that can work in thirty minutes. If a suitable replacement cannot be found, a different short term activity must be provided.
- Clear, well-illustrated instructions for the biodome construction must be included in the teacher notes.
- If the construction can be simplified, students could assemble the biodome themselves. This could replace the phase change material as a short term activity.

4.2.2 UV Detector

St. Angela's and Parmiter's schools used the UV Detector activity. The session at St. Angela's was afterschool and lasted 50 minutes. Twelve girls attended this session and broke up into four groups. Six students were interviewed. The teacher distributed the logbook, but could not show the film due to problems with her computer. The club at Parmiter's met for 30 minutes. Eight boys and seven girls divided themselves into four groups. Logbooks were distributed and the film was shown.

The Mars context, materials, and activities of the UV Detector session were all appealing to students. Students were visibly "wowed" and would try to get a close look of the UV-sensitive hands when the teacher showed them. While this reaction was observed at both schools, it was more pronounced at St. Angela's. Students also enjoyed being allowed to experiment freely with the materials. Many were excited about getting to work with the hand. One student at Parmiter's exclaimed "You got sunburned!" when she saw the hand change color.

Figure 13 shows that five students expressed particular enjoyment in the activity, while seven did not state this outright or had mixed feelings. Although a majority of the students had no strong opinion on the activity, none viewed it unfavorably. The students who expressed enjoyment indicated that they liked playing and experimenting with the hand and UV light. They also said that they enjoyed that the activity addressed the dangers of living on Mars.

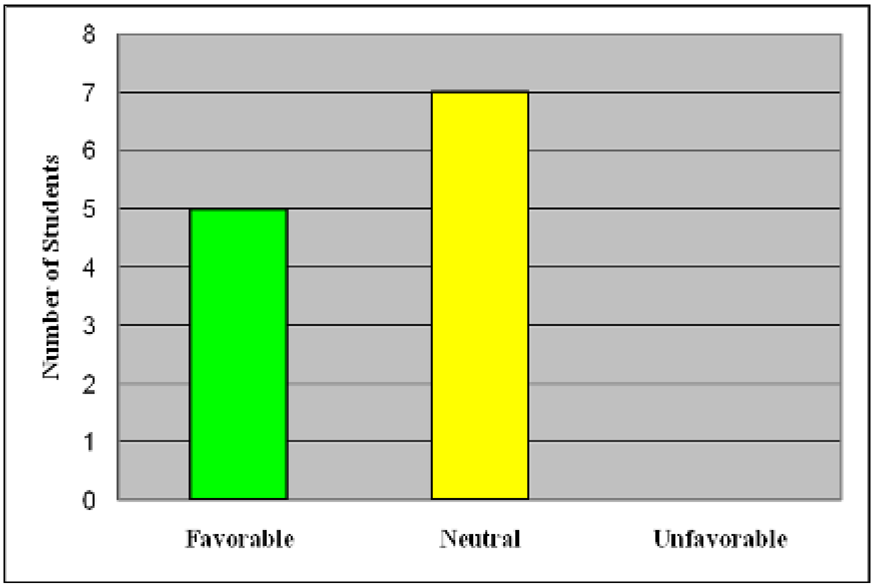

Figure 13: Student opinion of UV Detector activity

Unfortunately, the prototype UV LED lights did not work properly at either school. At St. Angela's, none of the LED lights worked and several of the lights functioned unreliably at Parmiter's. Due to these malfunctions, both teachers were forced to improvise with other battery-LED configurations or alternate sources of UV light. The teacher at St. Angela's specifically called attention to the failure of the lights during her interview. Many students (7/12) expressed difficulties using the materials (Figure 14). The students who had technical difficulties were frustrated and complained about how the LEDs did not function during the activity. One student at Parmiter's quickly became frustrated and exclaimed, "This will never work!" While teachers could work around the device malfunctions, they detracted from the enjoyment and educational value of the club session.

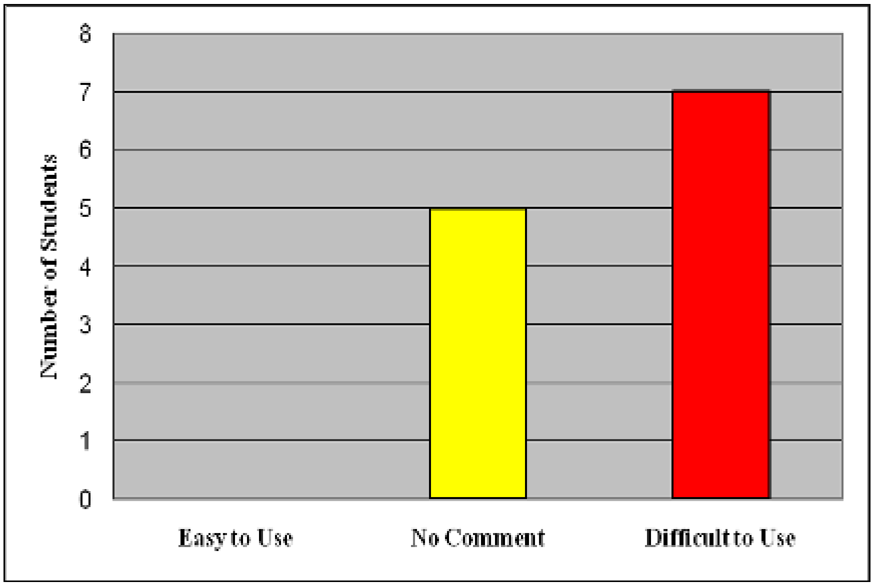

Figure 14: Student difficulty with UV Detector materials

Further complicating the technical difficulties, the teacher instructions failed to convey the fundamental concepts underpinning the activity. Both students and teachers did not fully understand the nature of the UV-sensitive hand. At Parmiter's, students believed that too much exposure would permanently change the color of the hand while the teacher was unsure. Some students also thought it was affected by artificial light. One group at Parmiter's tried to prevent any color change at all by covering the hand with excessive amounts of sunscreen, foil, paper and plastic. They did not experiment with nor explore the properties of the materials provided in the intended fashion. During her interview, the teacher at St. Angela's also requested that more information on the activity and materials be included with the boxes.

Evidently, the materials and instructions for this activity need to be modified to provide an activity that is engaging, functions reliably in a classroom setting, and has clear educational value. We recommend the following:

- A pre-assembled, fully contained UV LED light needs to replace the current UV LED light and battery approach.
- There should be a container included that students can use to measure the correct amount of sunscreen to apply.
- Information on how the hand is affected by the UV exposure and how UV exposure affects people should be included in the teacher notes.

- A cartoon person should be included along with the UV color change scale to depict how that color change on the hand would affect a real person.

4.2.3 Swipe Card

The Swipe Card activity was run at Tom Hood and Southgate schools. The session at Tom Hood was a short lunch session lasting only 25 minutes. Ten boys and four girls attended this session and, due to confusion on the part of the teacher and due to class timing, eight students from this school were interviewed. The teacher did not distribute a logbook to the students, but instead used a blank sheet of paper. The session at Southgate took place afterschool for 45 minutes. It was attended by five boys and one girl, all of whom were interviewed. Logbooks were distributed at this school. The crime lab film was shown at both schools.

We found one of the strengths of the Swipe Card activity was that students got very excited about the subject. They enjoyed the links to forensics and the television series, Crime Scene Investigation (CSI). The introductory film established these links by setting the scene as a break-in at the science museum. Using the swipe card and other evidence, the students must find the culprit. At Southgate, students were very excited and eager to provide their own thoughts and ideas during a teacher-led discussion on how to catch the culprit. Figure 15 shows that a majority (10/14) of students expressed interest in the CSI links. Students at Southgate stated that trying to catch the criminal was their favorite part of the activity. Additionally students at Tom Hood indicated that they wished they had been able to find time to do this part of the activity. Their school was unable to finish this part due to time constraints. Students at both schools were interested in exploring the materials further and wondered how a swipe card is actually read. The teacher interviews reinforced the finding that students really liked the links to real life, with a particular emphasis put on CSI by the teacher at Southgate.

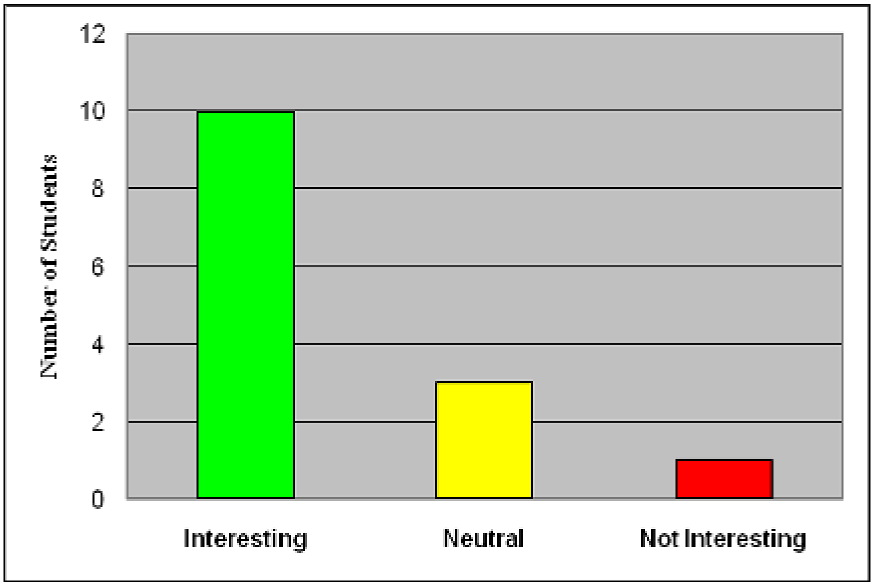

Figure 15: Student interest in CSI links

The largest problem with the Swipe Card activity was the difficulty students had getting a readable code. At both schools the students had to repeat the experiment multiple times to get a satisfactory code reading. Even with teacher help most students could not achieve this by the end of the session. One girl at Tom Hood experimented with her own methods of getting a readable code while other students where getting frustrated with the transfer method provided. Some students at Southgate got a readable code, but did not realize it and started over. In interviews, six of the 14 students expressed frustration getting the code and only one mentioned that the activity was easy (Figure 16). The teacher interviewed at Tom Hood raised the issue that the codes on the cards might wear off over time. The underlying problem with this activity is that many students had difficulty completing it.

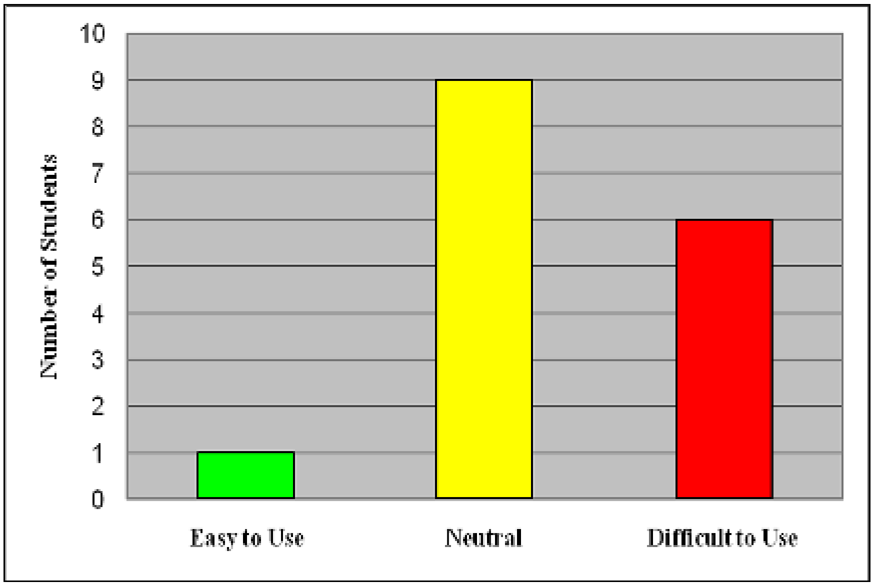

Figure 16: Student difficulty with Swipe Card materials

Another problem with the Swipe Card activity is the difficulty understanding and interpreting the suspect list and alibis provided. This is particularly important because solving the break-in at the science museum was one of students' favorite parts of the activity. The crime is meant to be solved over the course of the entire crime lab box but this is not made clear to the teachers. They believed that the Swipe Card activity alone could determine the culprit. For example, while we were observing the teacher at Southgate they had to ask our liaison if the crime could be solved after the activity. Both the students and the teacher showed signs of disappointment at her negative response. Another problem is that the nature of the alibis may have confused students at Southgate as they needed teacher assistance to find who could or could not be at the crime scene based on the times. For example one student said to the teacher "Sir, we don't know what to do." This indicates that the links between the card code, the alibi times, and the suspects are too weak for the box's target audience.

Several approaches need to be taken to address the problems we found with the Swipe Card activity. Our recommendations are as follows:

- The code needs to be easier for students to read and obtain. We have several ideas on how to do this. First, the coding system could be changed to a more readable one that uses larger or more obvious shapes. Second, the method students use to read the code can be changed to attain better results. This may involve using a more contrasting surface to read the black powder off of. One approach is to put a piece of paper over the card and brush the powder over the part of the paper that covers the magnetic strip. This may also remove the need for the tape transfer. Finally, including an example picture for students showing what a code looks like and how to decode it would both let the students know what to look for and help them in the decoding step.

- Whether or not the coding wears off over time or in proximity to magnets needs to be investigated. If either occurs, this information needs to be presented to the teachers.
- The suspect list should be simplified. It should simply state when suspects were seen at the museum so students can easily draw a connection to it with the time encoded on the swipe cards.
- A better explanation on how to use the suspect list should be included in the teacher notes.
- A separate suspect list that can be solved after just one activity should be included for clubs intending to only do the Swipe Card activity.

4.3 Teacher Resources

A major goal of the boxes is to make leading a club easier for the teachers. Our observations and interviews indicate that the boxes are very successful in this regard. Generally, teachers found the activities easy to prepare for and very adaptable. Unfortunately, several teachers found the teacher resources lacking. We found problems with the lack of information in the teacher notes. On the other hand, the PowerPoint and the posters were very well received.

Table 8 displays the teachers' responses with regard to the preparation of the activities. We found that, because they were provided with the resources of the activity, the boxes made the teachers' preparation easier. Four out of the six teachers spent only twenty to thirty minutes preparing for the session (Table 8). All of the teachers said the instructions were easy to follow. The Southgate teacher compared his experience to past activity preparations in which a lot of research and organization was required. Through this comparison, he claims that having all the resources in the box made the preparation much easier.

Teacher Interview	Activity	Instructions	Prep Time Required	Preparation
Southgate	Swipe Card	Easy to follow	20 min	Easier compared with past activity preparations.
Tom Hood	Swipe Card	Easy to follow	15-20 min	Made preparation easy because everything was provided.
Bramhall	Biodome	Easy to follow	Hours	Dome was a “nightmare” to put together.
Maidstone	Biodome	Easy to follow (but had questions)	30 min on biodome alone	Did not have as long to prepare as would have liked. Biodome difficult to assemble
Parmiter’s	UV Detector	Easy to follow	30 min	Did a dry run first to make sure it worked.
St. Angela's	UV Detector	Easy to follow	20-30 min	Not much preparation needed.

Table 8: Teacher preparation interview responses

Table 9 below recounts the teachers’ delivery of the activities. Teachers delivered the activities in different ways. Some teachers led their clubs in a more structured approach that emphasized the scientific method such as at St. Angela’s and Tom Hood. Others adopted a more informal delivery. For example, at Parmiter’s, the students were given complete freedom to explore. Another approach was taken at Maidstone in which the activity was set up as a competition. Lastly, some teachers attempted to incorporate additional enhancements to the activities. At Bramhall, the teacher created his own PowerPoint presentation to introduce the topic and it was noted that the teachers at Southgate, Bramhall, and St. Angela’s led their students through discussions. These observations indicate that the activities were adaptable to each teacher’s individual teaching style.

Teacher	Activity	How Teachers Delivered Session
Southgate	Swipe Card	Gave materials to students and let them explore. Helped students when it was needed. After the activity, he led a discussion.
Tom Hood	Swipe Card	Led students through the whole activity.
Bramhall	Biodome	Made his own PowerPoint to introduce the activity. Kept a discussion going throughout the session. Walked students through the activity.
Maidstone	Biodome	Made the activity a competition.
Parmiter’s	UV Detector	Allowed students to freely experiment.
St. Angela's	UV Detector	Led discussion to begin activity. Had the students set up the activity like a scientific experiment.

Table 9: Teacher activity delivery

Table 10 shows the time frame of each session, whether the activity was finished within the session, and if a discussion or if further experimentation was led. For the purpose of this analysis, we defined the evidence of the teacher’s ability to expand upon the activity to be their ability to lead discussions or complete further experimentation. We also defined the evidence of the activity’s adaptability to the time frame to be the observation of whether or not the activity was finished.

School	Time Frame	Finished?	Discussed	Further Experimentation
Southgate	Afterschool	Y	Y	N
Tom Hood	Lunch	Y	N	N
Bramhall	Lunch	Y	Y	N
Maidstone	Lunch	Y	N	N
Parmiter’s	Lunch	Y	N	N
St. Angela's	Afterschool	Y	Y	N

Table 10: Club time constraints

All of the clubs were able to finish the activities. They accomplished the core parts and obtained the necessary results. Clearly, all the activities were adaptable to the given time frames. Three schools discussed the activity during the sessions. Southgate was one of these schools and they talked in great detail about how to find a suspect and what methods other than swipe cards you could use. None of the schools, including those meeting afterschool, did any further experimentation. This may be a fault of the teacher notes for not providing clear extension activities or their intended use. Regardless of the absence of the further experimentation, we believe that the observations of the three clubs leading discussions provide evidence that the activities can be expanded upon. Since the clubs were able to complete the activities and those with the time were able to expand on them, the activities can be adaptable to the given time frames of the clubs.

The teachers' responses regarding the teacher notes are displayed in Table 11. It is evident that the teacher notes were confusing and did not contain enough information. Three out of the six teachers made a comment about the notes being confusing or not clear and one asked many questions that should have been answered through the notes. Comments were also made about adding in more information on how the activity works. The teacher at St. Angela's said that she knew how the activity worked because she teaches the subject at the A level but that other teachers might not have the same background. She concluded that this may be a problem for them when they attempted the activity and that it would be helpful to include more information in the teacher notes.

Teacher Interview	Activity	Teacher Resources
Southgate	Swipe Card	Had a problem understanding the notes the first time he read them.
Tom Hood	Swipe Card	Simple and straightforward but the two sections on the suspect information were very confusing.
Bramhall	Biodome	Sections for what you need to run the activity and the pictures included are helpful. Have different headings for clarity. Have a better Health and Safety section.
Maidstone	Biodome	Asked a lot of questions about how to do the activity during the interview. Teacher notes on phase change material should be included. Did not know how the activity was supposed to be done in groups.
Parmiter's	UV Detector	They were simple. Make them more concise. It contains a lot of explanation. Have somewhere an explanation of the hands.
St. Angela's	UV Detector	More teacher info would still be good for those without a background in the subject. Could contain more of an introduction. They were good for support, but not too leading.

Table 11: Teacher resources interview responses

As further evidence of the importance of clearer notes and more information, most teachers needed to ask questions of our liaison. These ranged from how certain materials work to how to do the next part of the activity. At Bramhall the teacher asked “How much of this [phase change material] do I need to put in?” We also observed many situations where students asked questions that teachers could not answer. At St. Angela’s, when they were completing the UV Detector activity, students asked how the UV-sensitive hand and the sunscreen worked. The teacher was not able to answer these questions. Evidently, the teachers did not have all the information they needed to run the activities successfully on their own.

Teachers’ reactions to the PowerPoint and poster are displayed in Table 12. The PowerPoint and Poster responses are contained in separate columns.

Teacher Interview	PowerPoint	Poster
Southgate	Claimed it was like a lesson, “Just what I wanted really.” Able to just go through instructions on screen.	Liked poster and its simplicity. Would put posters up everywhere to advertise.
Tom Hood	Liked the step-by-step instructions. It was good to see pictures so the teacher does not have to lead the students through the activity	It was interesting. Could have a more exciting title. Would use for advertisement.
Bramhall	Puts activity into the proper context.	“Smashing!” Would use them for advertisement. Said it would be good to have electronic version also
Maidstone	Needs to be short to accommodate lunch sessions. (i.e., fewer slides).	Looks clear and simple. Perhaps have some that just say science club. Would use for advertising around school and registers.
Parmiter’s	Was good but would only use the film or the PowerPoint in the beginning. Have no more than 5 slides because it gets too much like school.	Fine. Good way to advertise and the students can see what we are doing next week
St. Angela's	It was straightforward. Pictures are good to show and provide more help. Maybe include logbook hints	Did not have time to put it up but would afterwards.

Table 12: Teacher PowerPoint and poster responses

The teachers evidently liked the PowerPoint. Four out of the six teachers had a positive reaction to it (Table 12). At Southgate, the teacher said in his interview that the PowerPoint was “Just what I wanted really.” Many of the teachers informed us through the interviews that they liked the step by step instructions and pictures showing how to do the activity correctly. Some teachers, especially those who held the club sessions over lunch, suggested including a shorter version.

The teachers also liked the poster and all but one teacher claimed they would use it. The one who provided no comment had already posted it in the hallways. Many of the teachers also said that they liked the simplicity and potential of the posters. The only suggestions for improvement were minor and involved changing the wording of some parts.

The following steps should be followed to provide teachers with optimal resources:

- For all activities, more background information on the activity and materials need to be included in the teacher notes.
- More flexibility for different length club sessions should be provided. One option would be to provide a set of instructions for the activity that can be used in the average club session and supply options or ways in which the teacher can shorten or extend the activity to fit their time frame. A short and long PowerPoint presentation should be included so that teachers can use it according to their time constraints.
- More flexibility for different teaching styles should be included. Ideas for a less structured session should be provided in addition to step-by-step directions. Prompts for discussions and further investigation with their students should be provided.
- More links to the curriculum and to real life should be included.
- Every activity should have an extension idea centered on a competition.

4.4 Introductory Films

Each box contained an introductory film that provides a context for the activities in the box. The Crime Lab film is a news report about a break-in at the Science Museum that students need to solve. The Mars Mission film shows a movie director pitching an idea for a Mars mission. While the Crime lab film was well-received, the Mars Mission film was more problematic.

For the Crime Lab film, the reception was very positive. Both teachers at Southgate and Tom Hood said the film set the scene well and made it easier for them to introduce the activity and motivate the students. Both teachers could easily transition into the activity from the film and introduce the activity as solving a crime. At Southgate school, the teacher led a discussion about the evidence presented in the film and many students remembered key details about the suspect and the robbery. Many of the students were similarly enthusiastic about the film. Ten of the fourteen students gave the film favorable ratings (Figure 17). One student at Tom Hood school said that she thought the film was actual footage of a robbery. As the major goals of the films are to excite the students and to introduce the activity, this film clearly achieves these.

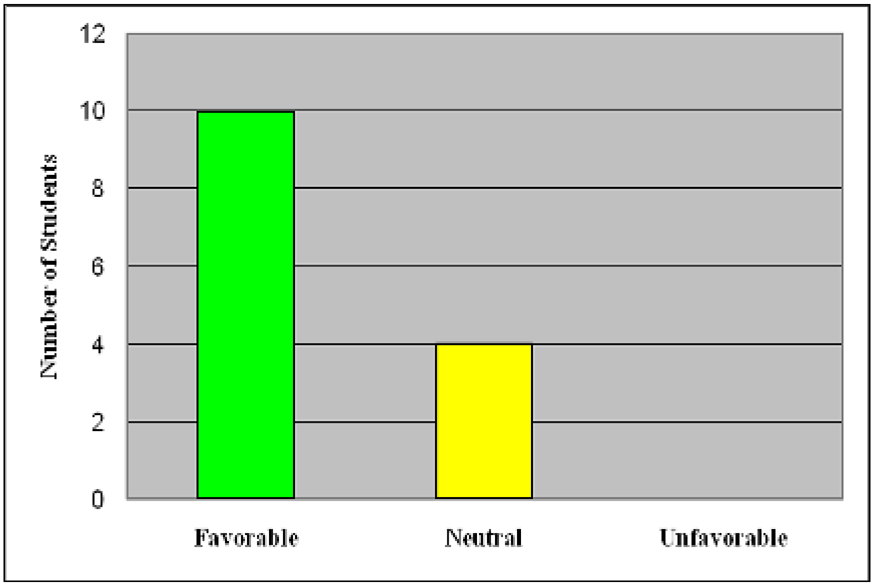

Figure 17: Student opinion of the Crime Lab film

The Mars Mission film fell short of achieving these goals. Teachers were split in their opinions of the film (Table 13).Three out of the four teachers disliked the context the film set for the activities. The teacher at Bramhall did not even show the film. Instead, he made up his own PowerPoint presentation to provide a better context and introduction for the Biodome activity. The teacher at Parmiter's School had trouble tying the UV Detector activity to the context set by the film and indicated that the ending of the film was confusing. These difficulties made the teacher's job more difficult and negatively affected the activity.

School	Teacher Responses
Bramhall	Did not show film since he thought his students would be confused by the context.
Maidstone	Liked how excited the film made her students.
St. Angela's	Could not show film due to technical difficulties. She could not see a link to the activities in the film.
Parmiter's	Did not like the film-making context and thought the film drifted too far away from the science of the activities.

Table 13: Teacher reactions to the Mars Mission film

The Mars film received mixed reviews from the students (Figure 18). Five students gave favorable reviews, five negative reviews, and three were neutral (one student gave no response at all on this item). Several students said that they would rather hear from astronauts instead of the movie director. Others wanted to hear more about Mars and an actual mission. The students said that they liked the references to celebrities and movies. Although the film excited these students, it would be better if the science connections were what excited them. This parallels concerns raised by the teachers. Clearly the Mars film is not effective as a vehicle to introduce the activities.

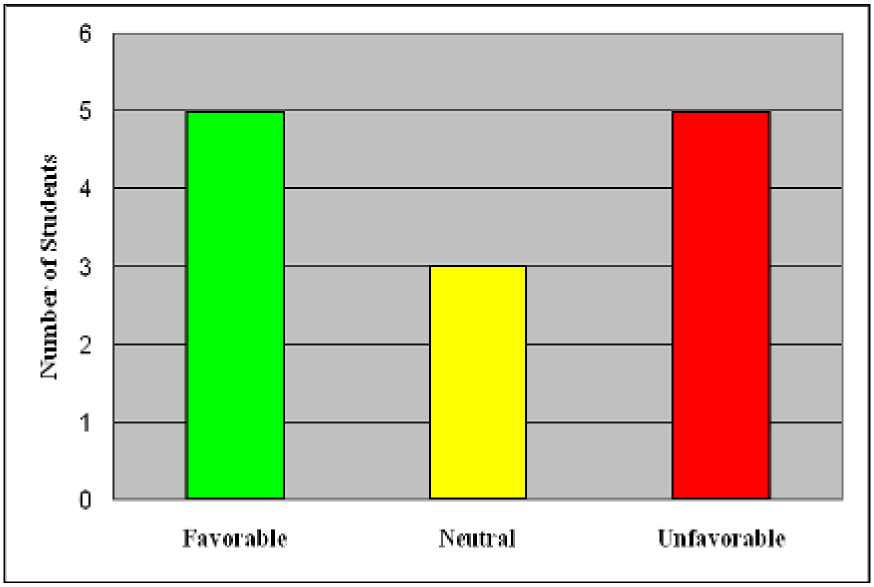

Figure 18: Student opinion of the Mars Mission film

Since remaking films is too time consuming and expensive, our recommendations for the films focus on editing and minimize reshooting. These recommendations are:

- The end of the Mars Mission film needs to be changed in order to present a different context. This change should cut out the current ending and instead make references to the importance of making science fiction films look realistic.
- Make the CCTV footage in the Crime Lab film look grainier and more realistic and give the newscaster a newsroom background.

4.5 Student Logbook

The student logbook produced mixed reactions. Teachers introduced the logbook to students in different ways. Table 14 shows both how the teacher instructed the students how to use the logbook and how the students reacted. What stands out is that when the teacher specifically instructed the students what to write in the logbooks, the students did as they were told. However, when the teacher left it more open or did not keep reminding their students to keep notes, the students tended to ignore the logbook. One student at Parmiter’s even ripped it up to use it as paper in the UV Detector experiment. Within each class, there were often some students who kept diligent notes while others who never opened the logbook.

School	Teacher Actions	Student Actions
Southgate	Used logbook to find clues and to put code tape	Most students followed instructions, though a few did not at first.
Bramhall	Distributed one page from logbook. Told students to record change in temperature over time	Most students took some notes, though some were more diligent than others.
Maidstone	Did not receive logbooks	N/A
St. Angela's	Told students to write down notes and experiment conditions	Several students needed to be constantly reminded to use it.
Parmiter's	Told students to write down notes	Most students ignored logbook, some even tore it up to use for the activity.
Tom Hood	Did not receive logbooks, used another sheet of paper for notes	Students put code tape on paper and wrote down decoding.

Table 14: Club use of the logbook

The teachers’ reactions to the logbook in interviews can be found in Table 15. Most teachers liked the fact that the students could have something of their own to write notes and tape things in. The students could then take it home as a souvenir. One problem with the logbooks was that teachers had trouble assembling them correctly. At Southgate and St. Angela’s, the teacher did not fold the logbook correctly and it confused the students. One student complained that his logbook fell apart during the activity. In other cases, the teacher did not print any logbooks and we had to show the students logbooks that we brought to ask them what they thought of them. There were no instructions included with the teacher resources on how to put together the logbook and this led to some confusion.

School	Teacher Responses
Southgate	Liked the CSI links as well as giving the students a place for notes.
Tom Hood	Good place to put code tape and take notes. Suggested putting more prompts and instructions in it.
Bramhall	Had trouble putting it together.
Maidstone	Liked the interesting facts and giving space for notes.
St. Angela's	Good for notes and drawings. Students would like have them to take home.
Parmiter's	Thought it brought the whole box together well.

Table 15: Teacher reactions to the logbook

While students may not have been excited about the note taking sections, the majority liked the logbooks as a whole. 26 out of 39 students had a favorable opinion of them (Figure 19). Many students said that they really liked the information bits on the notes pages and the two pages in the back that contained a great deal of information on the background of the activity. This was true for both activity logbooks. Girls in particular liked the patterns and colors used in the Mars Mission logbooks. Several students mentioned that they liked the note writing sections, but one said he thought that it was too much like regular class. For the most part, students and teachers liked the logbook, just in different ways.

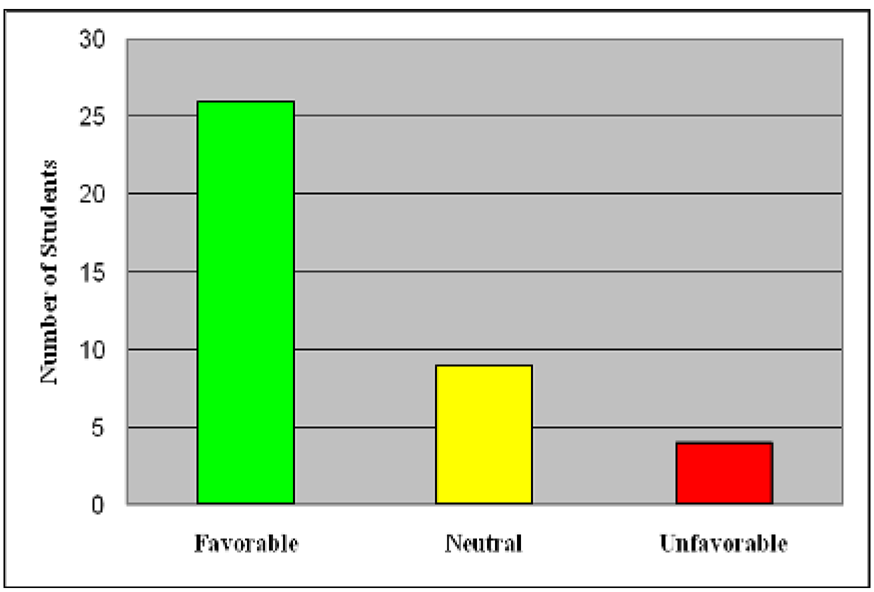

Figure 19: Student opinion of the logbook

The following recommendations address the problems presented with the logbook:

- More directions are needed in the teacher notes on the purpose and use of the logbook.
- Assembly instructions need to be included in the teacher notes. These instructions could be as simple as including pictures showing where to fold the pages and what the logbook should look like.
- Include prompts in the logbook for students. These would help give students ideas of what to write in the logbook without the teacher needing to tell them.
- More pictures and facts should be added to the logbook to boost its appeal to students.

4.6 Implementing Selected Recommendations

After analyzing the data and developing recommendations, we proceeded to implement a some of them. We selected based on how important the recommendations were as well as whether we had the time or capability to implement them. Table 16 and Table 17 show all of the recommendations we made with those we chose to implement highlighted. Priority was given to getting the activities to work and providing more information and extension activity ideas to teachers. We also developed a teacher resource activity that will go on the museum's website. A summary of these extension activities we developed can be found in Appendix H: Extension Activity Ideas. We evaluated our suggested improvements in a focus group of museum staff who have experience in outreach.

Biodome	UV Detector	Swipe Card
Replace phase change material	Simplify LED light	Simplify reading and decoding code
Biodome assembly directions	Sunscreen measuring container	Investigate code wearing off
Have students assemble the biodome	Information on hand and UV radiation	Simplify suspect list
	Cartoon illustration of UV damage	Explain how to use suspect list
		One activity solvable suspect list

Table 16: Recommendations for activities; highlighted recommendations were implemented

Teacher Resources	Films	Logbook
More background info for all activities	Change Mars Mission ending	More directions on purpose
More flexibility for short and long club sessions	Minor edits to Crime Lab	Assembly instructions
More flexibility for different teaching styles		Include prompts in the logbook
More links to curriculum and real life		More pictures and facts
Competition extension activity		

Table 17: Recommendations for supporting materials; highlighted recommendations were implemented

The improvements for the Biodome activity included clarifying the teacher notes and creating instructions on how to assemble the biodome. We tested different amounts of nutrient gel and different seeds to see what amounts yielded the best plant growth. Our results were included in the teacher notes. The problem with the phase change material was discussed in the focus group. One person suggested having students build a thermostat for the biodome that could regulate the temperature. If this works, it could take the place of the phase change material. We recommend looking further into this idea. The assembly of the biodome went well. Both groups could assemble the dome in a short amount of time. There was some confusion over the instructions which we addressed. These instructions can be found in Appendix I: Biodome Assembly Instructions.

The Biodome activity extension idea was based on demonstrating that plants produce oxygen. To do this, each of the two groups placed an aquatic plant into a clear small cup and submerged into a large bowl filled with water. While still submerged, the cup was flipped upside-down and left to rest on the bottom of the bowl. If left for ten minutes, the amount of air trapped under the cup increases noticeably. Focus group participants thought that it would be good to show how plants produce oxygen and that students would like the activity.

The problem we fixed with the UV Detector activity was finding a good method of measuring the proper amount of sunscreen to apply to the UV-sensitive hand. The solution is to use the small plastic cap from the packaging for the batteries for the UV LEDs. We wrote directions to include in the teacher notes. The consensus from the focus group was that our measuring tool was easy to use. We therefore recommend including the measuring tool and instructions on how to use it with the UV Detector activity.

Our UV Detector extension activity was to conduct a Shade Audit, which is an assessment of the school grounds and their ability to provide protective shade. Students could observe where many students gather and whether or not those areas are protected from the sun. The general consensus of the focus group was that it was good to raise awareness among the students of UV radiation and methods to protect against it.

Since the major problem with the Swipe Card activity was getting a readable code, we researched and tested alternative methods. The problem with the current coding system is that it relies on vertical lines. These lines do not show up well with the powder. To fix this, we designed new coding systems that relied on different symbols that show up much more easily. We also found that placing paper over the card and brushing the metal powder onto the paper shows up much better than trying to see black powder on a black magnetic strip. The focus group tested our new coding methods and had no trouble encoding or deciphering them. We recommend that the activity use our new coding system since it is much easier to read than the current one.

The Swipe Card extension activity involves encoding a time by putting canisters containing magnets and canisters not containing magnets into a certain order. Students will then pass the canisters in order over a compass to see whether or not they contain a magnet. This is a simplification of how swipe card machines read the magnetic code. In the focus group there was some initial confusion about how the systems worked, but they really enjoyed the activity. They felt that it would be an enjoyable activity for students as well.

5. Conclusion

We found that the Science Museum’s boxes provide engaging activities that offer an enhanced club experience for both students and teachers. The students were excited by the new experiences the boxes provided through their exotic materials and unique content. Teachers responded positively to the idea of a resource that includes everything necessary to run an activity, especially one with strong links to the curriculum and to the students' lives. We identified several problems with the materials functioning poorly or not being flexible for all teachers to use in any club setting. Future development of similar resources should focus on incorporating these positive aspects of the boxes while running similar evaluations to identify potential problems. Such a process will provide students and teachers with the best possible resource.

Student interest in the activity is directly tied to how interesting the materials are and to their ability to relate to the motivation for the activity. There must be an initial “wow” factor that entices the students and captures their attention. A captivating introduction such as the Crime Lab film can really set the stage for the activity. Maintaining this interest is essential and any problems with the mechanics of the activity will detract from it. Whenever the materials failed to work as intended, student frustration and disappointment followed.

Teachers are also negatively affected by materials that fail to work. Failures make their jobs more difficult as they must improvise a solution. Confusion over lack of proper instructions also detracts from the teacher’s experience. The major goal of the science boxes is to provide reliable resources for teachers that ease their running of a science club. In several cases, most notably the Biodome activity, problems with the materials and instructions meant this was not achieved. Properly working materials and clear instructions need to be provided in order to attain this goal.

All teachers are faced with the challenge of adapting resources to their individual styles and allotted time frames. We observed that each teacher delivered the activity in a different manner. It would be beneficial if the teacher instructions included more flexibility for style variations and time constraints. Such built-in flexibility would allow teachers to spend less preparation time trying to adapt the activity on their own. Any activity intended to be used by teachers needs to be adaptable in this fashion.

We learned that many problems arose in the development process because of poor communication with the museum's suppliers. One example was the problem with the phase change material used in the Biodome activity, which did not function according to the needs of the activity. This misunderstanding arose from miscommunication about the nature and objectives of the activity. Supplies for the activities often arrived late and could not be adequately tested before they were distributed to the clubs. Many problems at the clubs could have been prevented with adequate pretesting. Any future project should strive for better communication with suppliers to prevent these problems.

The recommendations that we made for the boxes addressed many of these problems. Ensuring the activities function as intended was the highest priority. Alterations were made to the materials and mechanics of all three activities to address the problems we found. The teacher instructions were clarified and expanded for each activity as well. We tested our improvements with a focus group and made adjustments as needed. While much work remains to be done, our improvements fixed the core problems with the activities. Since any prototype resource will have unforeseen problems, evaluation using protocols similar to the ones developed for this project will be necessary. We believe any future project being designed for students and teachers can benefit significantly from our work. The Science Museum can use our results to further develop the boxes and create new projects that will enhance their teacher resources. The insights and improvements provided by our evaluation protocol prove the need for this type of assessment in future endeavors. With continuing improvements in accordance with our recommendations, the boxes will be able to engage students and provide teachers with a valuable resource.

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Appendix A: Initial Protocol Worksheets

Observation Protocol

Date of observation:
School:
Number of students: (/)
Start time:
End time:

1. Rate from 1 to 7 the kits ease of use of the kit for the teacher.

   (Unable to complete) (No Problems)

   1 2 3 4 5 6 7

2. Rate from 1 to 7 the kits ease of use of the kit for the students.

   (Unable to complete) (No Problems)

   1 2 3 4 5 6 7

3. Rate from 1 to 7 if the materials in the kit were sufficient to complete the activity

   (Nothing included) (Everything included)

   1 2 3 4 5 6 7

4. Rate from 1 to 7 how often the teacher needed to keep the students focused on the activity

   (Constant Reminders) (No Reminders)

   1 2 3 4 5 6 7

5. Estimate how many students are engaged in activities other than the kit activity (i.e. outside conversations, homework, playing, etc.)

   0% 25% 50% 75% 100%

6. Circle any safety hazards that exist within the activity

   Chemicals Electricity Fire Sharp Objects Heavy Objects None

Teacher Interview Questions

1. Do you feel that this kit has made running an activity for the science club easier or more difficult?
2. Were the instructions included with the kit easy to follow? What could be improved?
3. Could you complete the activity with just the materials included with the kit?
4. Do you feel that the activities included in the kit were enjoyable to your students and to KS3 students in general?
5. Do you feel that this activity would only appeal to certain students or to the majority of those who participate in your STEM club?
6. How well do the activities match up with the British Curriculum?
7. Will the activities in this kit promote an interest among your students in STEM subjects?
8. What would you suggest for improvements for these kits, in either materials or activities?

Student Pre-Survey

Circle the response that best describes your feelings about each statement:
SD= Strongly Disagree; D= Disagree; N= Neutral/Don't know; A= Agree; SA= Strongly Agree

What is your favorite subject?

Math	Science	History
English	Religion	Other: ________________

What is your favorite type of school activity?

Experiments	Demonstrations	Contests
Taking notes	Doing problems	Other: _________________
Labs	Hands-on Activities	

I find STEM subjects to be interesting.	SD	D	N	A	SA
I am looking forward to math and science courses in high school.	SD	D	N	A	SA
I would like to have a job that is related to STEM subjects when I get older	SD	D	N	A	SA
I have given a lot of thought to my future career.	SD	D	N	A	SA

Student Post-Survey

Please Circle: Male Female

1. Was the activity:

   a) fun?

(No fun at all) (A lot of Fun)

1 2 3 4 5 6 7

   b) hard?

(Very Easy) (Average) (Very Hard)

1 2 3 4 5 6 7

   c) confusing?

(Not confusing at all) (Very confusing)

1 2 3 4 5 6 7

   d) exciting?

(Very boring) (Average) (Very Exciting)

1 2 3 4 5 6 7

2. Would you want to do another activity like this during your club?

YES NO

Circle the response that best describes your feelings about each statement:
SD= Strongly Disagree; D= Disagree; N= Neutral/Don't know; A= Agree; SA= Strongly Agree

I find STEM subjects to be interesting.	SD	D	N	A	SA
I am looking forward to math and science courses in high school.	SD	D	N	A	SA
I would like to have a job that is related to STEM subjects when I get older	SD	D	N	A	SA
This activity has increased my interest in STEM subjects	SD	D	N	A	SA

What do you like to do on your free time (interests/hobbies/sports)?

What would you like to do for a career?

What questions do you have from doing the activity?

Has the activity changed your opinions on STEM subjects? If so, how?

Student Interview Questions

1. Did you enjoy the activity?

    Yes: What was your favorite part?

        Was there anything you disliked?

    No: Why not?

2. Were you interested?

    If Yes: What part was the most interesting to you?

    If No: Why not?

3. Did the activity make you more interested in the subject?
4. Was it confusing?

    If Yes: when and why?

5. Did you learn anything from the activity?

    If Yes: What?

6. Can you think of anything to improve on?
7. Would you like to do another one of these activities in the future?

Appendix B: Model of Success for Boxes

Teachers:

- Quick and easy preparation
- Strong science/STEM content
- Supporting materials are easy to understand for every level of confidence
- Supporting materials provide them the opportunity to deliver the activities as short or long term projects
- Supporting materials provide enough ideas how to deliver
- Activities allow teachers to put their own style and input in it
- The films set the scene for them

Students

- They enjoy the activities
- They can complete the activities
- In the end, they achieve something as an end product that they like
- They feel that the content is relevant to their lives
- The films make them excited to do the activities
- They learned something new from watching the film
- The student logbooks are like an award for them
- The students use the logbooks as a record of their experiments

Appendix C: Observation Protocol

Observer:
Date of observation: Activity:
School name: Age group:
boys in club: in group: # girls in club: in group:
Start time: End time:

Prompts for notes…	**Notes**
Teacher Are there any difficulties running the activity? (actual activity, directions, questions) How is the teacher delivering the activity? Is the teacher confident? (are they reading off the paper) How did the teacher help/assist the students? Is the teacher visibly enthusiastic about the activity? (animated, excited, getting into it)	

Student	
How do they react to the film?	
Do the students expand on the activity on their own? (asking questions, making things)	
Body language of the students (on task, involved with activity)	
Do the students discuss the activity with their peers or talk about unrelated things?	
How do students interact with the logbook?	
Does the teacher use extension activities or links to real life?	

Appendix D: Teacher Interview Questions

Observer:
Date of observation: Activity:
School name: Age group:
boys in club: in group: # girls in club: in group:
Start time: End time:

Hi, my name is…we are working at the Science Museum to improve these science boxes. These boxes are still in the prototype phase and your opinion is important for their improvement.

Prompts for notes…	**Notes**
What did you think about the session? Do you feel that the activity was enjoyable for all of your students? (Probe) Based on gender, aptitude, interests, background, etc.	
Teacher Resources How did you adapt this activity for the students, if at all? (Probe) Why did you make these changes? How long did it take to prepare for the session? How do you feel about the structure of the teacher notes?	

Were the instructions included with the box easy to follow? (Probe)What could be improved? What did you think about the extension activity ideas? What did you think about the content of the activity? (Probe) Links to real life etc. What links do you see to the National Curriculum?	
Other resources *Next, I'd like to ask you some questions about the PowerPoint. Obviously, it's only a prototype but it's there to give you an idea what we could offer you.* What do you think about the PowerPoint? (Probe) Is there anything you would like to see improved? What do you think about the poster? What would you use the poster for?	

Activity	
What is your opinion on the introductory film? (Probe) Do you have any suggestions for improvement?	
What is your opinion on this version of the log book? (Probe) Specifically its content	
How do you feel the resources such as the teacher notes, PowerPoint, etc. have affect your running of the activity?	
Do you have any additional suggestions for this session? (Probe) Preparation or materials	
Thank you!	

Appendix E: Student Interview Questions

Observer:
Date of observation: Activity:
School name: Age group:
boys in club: in group: # girls in club: in group:
Start time: End time:

Hi, my name is…we are working at the Science Museum to make these boxes better. Your honest opinion would really help us.

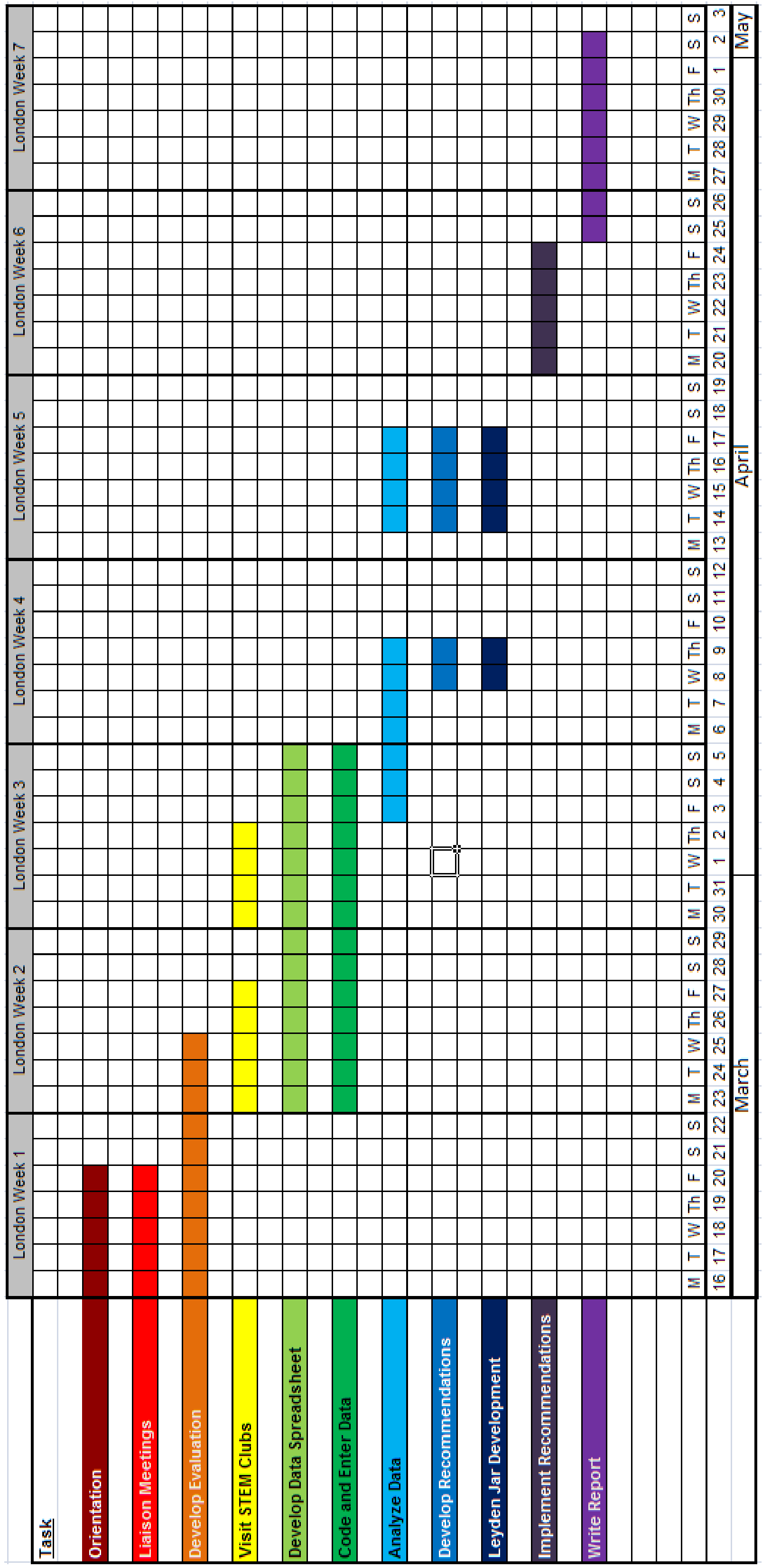
Prompts for notes…	Notes
What did you think about the session?	
Activity What did you like best about this activity? What did you like least about this activity? What have you heard about (Activity Content) (Probe) What and where? What else would you like to know about (Activity Content)? (Probe) If yes, what?	

What do you think this activity has to do with real life? What else would you like to do with these materials?	
Film What do you remember from the film? What did you think about the film?	
Log Book How did you use the log book? What did you think about the log book? Thank You!	

Appendix F: Data Analysis Spreadsheet Example

	Quick and easy preparation	Strong science/STEM content	Supporting materials are easy to understand for every level of confidence	Supporting materials provide them the opportunity to deliver the activities as short or long-term projects	Supporting materials provide enough ideas how to deliver	Activities allow teacher to put their own style and input in it	The film set the scene for them
Teacher Observations	Had trouble building biodome/Teacher enthusiastic and confident/Teacher put together biodome incorrectly		Used PowerPoint slides in activity/Teacher unsure of how to use gel crystals		Used PowerPoint slides in activity/Used analogy throughout of being on Mars and needing to survive	Opened up discussion about the environment on Mars/Gave students materials to study temperature and let them try to figure out what to do first	N/A
Student Observations		Know that biodome acts as a heat insulator/Students experiment with color changing thermometer/Students know about Eden project/ Use pipette to measaure waster for the seeds					N/A

Appendix G: Gantt Chart



Appendix H: Extension Activity Ideas

Biodome: Underwater Plants

This activity focuses on demonstrating that plants produce oxygen, a gas essential for human survival. You need an aquatic plant, a clear small jar or cup, a large bowl or pot, and water to complete this activity. A straw is optional. Fill the bowl with water, so it's deeper than the cup. Place the plant inside the cup and then submerge both with the opening facing upwards. Make sure that all the bubbles float out of the cup or tap it until they do. Then while still submerged, flip the cup upside-down and let it rest there. Dump out some extra water from inside the bowl, but make sure that all parts of the cup opening remain underwater. One idea to test is to try blowing bubbles into the water with the straw, but make sure none of the bubbles go into the cup. (This is increase the amount of dissolved carbon dioxide in the water. Plants need this carbon dioxide to produce oxygen). Then place the bowl and cup setup in the sun and observe about every 15 minutes to check for bubbles that collect at the top of the cup. These bubbles are full of oxygen. If you need to demonstrate its oxygen, try collecting the bubbles when they are fairly large and igniting them. The "pop" is indicative of the combustion that occurred when the flame encountered the oxygen bubble.

UV Detector: Shade Audit

An idea for an extension activity would be to have your students conduct a Shade Audit. A Shade Audit is an assessment of the school grounds and their ability to provide protective shade for students. Your students would map out the school grounds indicating where shade areas exist, where students like to spend their time, where student seating currently exists, what areas are risk zones (a lot of student use but not a lot of shade or protection), and what types of shade are most popular with the students. From these results the students can conclude what areas are best for protection on the grounds and what areas, due to their popularity, need more protection. From this need, the students can propose measures to be taken that will allow for better protection in the popular areas. One idea is to plant a tree or make a shade structure. Possibly they could also conclude how to make the best areas of protection more popular. One idea would be to provide more seating in those areas. If time allows, the students can then make up a poster to be put up around school that displays the best areas for their fellow students to spend their time outside and possibly began a campaign to get the needed shade in the current popular areas.

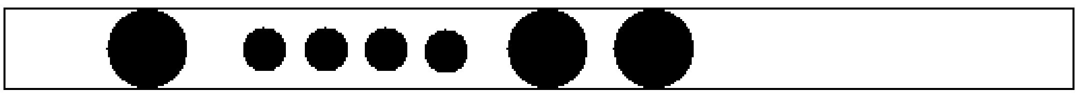
Also, if there is enough time or you want to do this activity over a couple of sessions, you can have the students observe what times of the day the different areas get the most sun and the most shade. This could also be displayed in the poster to advise their fellow students on the best times to use each area.

Swipe Card: Magnetic Pattern Reader

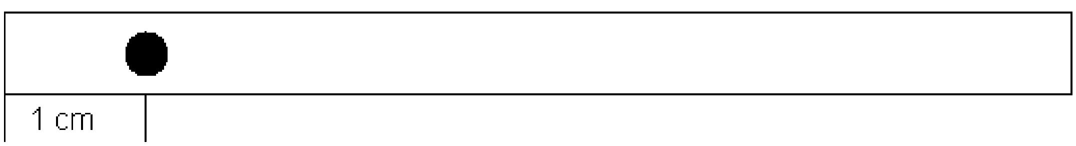
Students can come up with their own coding systems. They only have to wipe the magnetic strip first (by swiping the magnetic strip with the large, powerful magnet) before putting the round magnets in the place/s they want for their code. Now, groups can challenge each other by exchanging their coding systems and their cards holding their self-made code.

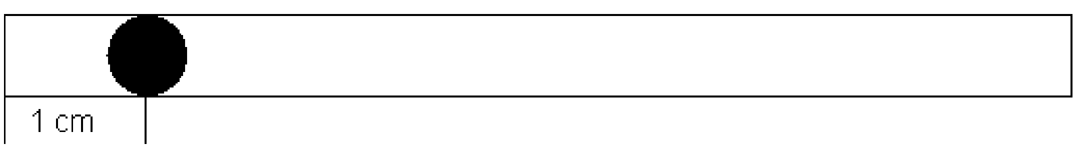
Here are some coding systems you may consider using with your students or giving to your students as example for when they design their own. We recommend using only circular magnet patters as they show up the best, but other shapes can also work.

1. If the pattern begins with a large circle the time is PM. Otherwise the time is AM. Small circles following that represent 1 hour increments, large circles represent 10 minute increments. The disadvantage to this system is you may run out of room on the card for certain times. The example below shows the time 4:20.



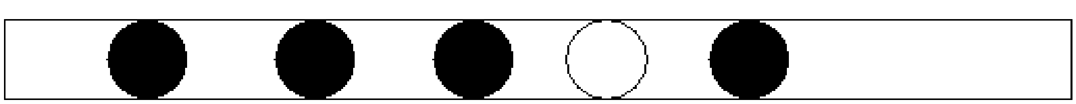
2. Only one circle is coded on the card. If the circle is large it indicates an AM time, a large circle indicates a PM time. Every ½ cm the circle is placed from the left edge of the card indicates one hour's time. This system requires the students to do fine measuring and math to get minutes. Also the times may not be exact. That said you may find this system useful if these are skills you are trying to teach your students or want to take an average time from between groups. The examples below indicate the times of 2:00 AM and 2:00





PM respecify.

3. Another method is to encode the time in a 24 hour clock in binary on the card. Five circles have to potential to be placed evenly along the card. The first circle, if present, indicates 1 hour's time. The second represents 2 hours, the third 4 hours, the fourth 8 hours, and the fifth 16 hours. This example is most accurate to how computers encode and read information, however it may be difficult to determine the correct spacing and it is only possible to encode in hour increments. The example below represents the time 23:00 or 11:00 PM.



You could also discuss what other evidence may have been left at the scene to explore in the future.

It has been found that students performing the Swipe Card activity want to know how swipe cards are read. The following extension activity aims to give them some sense of this. You will need for each group (2 or more) of students:

- 6 or more small opaque containers, preferably numbered sequentially - examples include film canisters, small jars wrapped in tape, prize containers from inside Kinder Eggs, etc.
- a compass
- a magnet for each container - more powerful is better, but risks damaging the compass such that it no longer points true north
- some small non-magnetic objects of approximately the same weight

In this activity students will be given a coding system. One student will encode a time in the series of canisters by placing either magnetic or non-magnetic items inside them in a particular order. The second student will then swipe the containers over the compass in the proper order. Containers with magnets inside will cause the compass to move, the others won't. The second student can then decode the message based on which container had magnets in them. The non-magnetic objects force the students to decode based on the magnetic reaction rather than whether or not an object rattles around inside the container.

This shows students how magnets can interact with other devices even though the device in question may not be able to "see" the magnetic pattern. This should give students a general idea of how a swipe card reader can pick up and decode a magnetic patter. To tie the activity back to the Swipe Card activity you can have the students encode times. You might try to get them to be able to code a time with fewer and fewer containers. At an hour's precision you can encode a 24 hour time in as few as five containers. This relates to binary, the base 2 counting system that computers store and process information.

Here's a coding system that uses 8 containers:

1st container	2nd container	3rd container	4th container	5th container	6th container	7th container	8th container
Magnet Value = 4 hours	Magnet Value = 4 hours	Magnet Value = 4 hours	Magnet Value = 4 hours	Magnet Value = 4 hours	Magnet Value = 2 hours	Magnet Value = 1 hour	Magnet Value = 1 hour

Here's another that uses only 6 containers:

1st container	2nd container	3rd container	4th container	5th container	6th container
Magnet Value = 10 hours	Magnet Value = 10 hours	Magnet Value = 5 hours	Magnet Value = 2 hours	Magnet Value = 1 hour	Magnet Value = 1 hour

Here’s a 5 container coding system that is similar to one way (signed magnitude) computers code positive and negative numbers, in this case AM/PM:

1st container	2nd container	3rd container	4th container	5th container
Magnet = PM, No Magnet = AM	Magnet Value = 8 hours	Magnet Value = 4 hours	Magnet Value = 2 hours	Magnet Value = 1 hours

Note in this last system that there is only one way to represent any given time.

Mars Mission Box: Mars Habitat Competition

The teacher can explain all the tests that the structure will have to go through to win. Materials are distributed and each group gets thirty minutes to build their habitat to protect astronauts from the dangerous Martian environment. The tests will be run by the teacher. Then groups will vote on which structure is the best looking.

Ideas for Construction Materials

Drinking straws	Elastic bands
Paper Clips	Polystyrene sheets
Printer paper	Felt cloth
Colored Construction Paper	Cardboard
Aluminum foil	String
Bubble wrap	Pipe cleaners
Index Cards	Popsicle sticks
Saran wrap	Sticky tape

Competition

Volume Test

The astronauts will need to have enough room to live and work in. Any structure that covers the shoebox completely earns +10 Points.

UV Test

UV radiation on Mars is much higher than that on Earth. Without a suitable habitat, astronauts will not be able to take off their protective spacesuits. Place the hand inside the structure and put the structure in sunlight. No color change in the hand must take place after one minute for +10 Points. Only a small color change will net +5 Points.

Temperature Test

The temperature on Mars can reach an extreme cold of -60°C so any habitat will have to be well insulated. A beaker of hot water is placed inside the structure by the teacher with a thermometer inside. Whichever structure keeps the water the hottest after five minutes gets +20 Points. Second and third place teams get +10 and +5 Points respectively.

Weight Test

Any materials used in the habitat will have to be carried in the rocket. A lighter rocket will be easier to launch and require less fuel. Weigh the entire structure. Whichever structure is the lightest +15 Points. Second and third place teams get +10 and +5 Points.

Strength Test

Any structure that will house astronauts on Mars will have to be tough and sturdy. Each structure must support a 500 g weight anywhere on its roof for ten seconds to get +10 Points. +20 Points if the structure can support 1 kg.

Aesthetics Test

The best looking structure based on voting results gets +10 Points. Second place gets + 5 Points.

Competition Score Sheet

Test	Scoring			
Volume Test	+10 if it covers the object			
UV Test	+ 10 for no color, +5 for little color			
Temperature Test	+20 for 1st +10 for 2nd +5 for 3rd			
Weight Test	+15 for 1st/+10 for 2nd/+5 for 3rd			
Strength Test	+10 for one weight, +20 for 2			
Aesthetics Test	+10 for 1st/+5 for 2nd			
Total				

Website: Lightning Jar

Use the power of static electricity to light up a light bulb or shock your friends.

Year groups: Key Stage 3

Educational Objectives:
Students will discover how a static charge is built up by experimenting with a Leyden Jar, a device that stores electrical charge. This is a precursor to the modern capacitor. Students can learn practical applications of electrical principles.

Key Student Learning

- Static electricity can be transferred from one material to another
- Static charge can be stored
- Some materials work as insulators and some as conductors
- Closed and open circuits
- Voltage, current, and resistance

Materials, per group

- polystyrene cup
- Aluminum foil
- 2 plastic cups
- Aluminum pie plate
- Sticky tape
- Piece of polystyrene
- Piece of wool

Teacher's materials

- 6-watt fluorescent light bulb

How to run the Leyden Jar activity

1. Creating the Leyden Jar
    - Wrap foil around each plastic cup, making sure it's as smooth as possible and tape the foil together. Only tape the foil to itself, do not tape the foil to the cup. Keep a 1 cm space from the top and bottom of the cup.

- Remove foil from one cup and place it inside the other cup

- Create 2 small foil strips and tape one to each layer of foil, having them connected on opposite sides of the cup.

- Put the foiled cup in the other cup so it covers the outer layer of foil

- Fold the aluminum strip of the outer aluminum layer over the plastic cup.

2. Create the Charge collector
    - Tape the open end of a polystyrene cup in the middle of an aluminum pie plate

3. Charging
    - Rub the piece of polystyrene with wool cloth for 2 minutes

    - Place piece of polystyrene on flat surface and place the charge collector on top using the cup as a handle

    - After collecting the static electricity into the plate, hold the jar while touching the folded-over tab (do not touch other tab or let go of tab once you've started collecting, this will discharge any collected charge)
    - Touch the tab sticking out to the charge collector (you might hear a crackle or see a small spark)

- Charge the Leyden jar up by repeating the cycle of rubbing the polystyrene, collect charge in the plate and touching the strip of the jar to the plate – make sure you do not let go of the opposite strip.

4. Lighting the bulb
   - Have one person (or yourself) hold one end of the bulb without touching any of the metal contacts.

   - The student with the jar should touch the loose tab of the jar to both metal contacts of one end at the same time
   - Enjoy!

Practicalities

- Might want to turn off lights and close blinds when trying to use the light bulb to see it light easier.
- Rotating who builds up the static charge will help get everyone involved
- Many factors affect the Leyden jar's effectiveness including humidity, temperature, and foil smoothness

Warnings

- Small static shocking may occur

Discussion

- Why do we use wool to get a charge? How do other materials compare?
- Where is the charge stored in the Leyden Jar?
- What happened when you touched the bulb to the Leyden jar?
- What are the sparks you see when you touch the aluminum plate?
- Does the amount of time you spend charging affect the amount of charge you build up?
- Why isn't the charge in the cup dangerous?
- Where did the charge come from and where did it go?

Extension

- Hook a real capacitor into a circuit with a battery. Unhook it from the battery and then use it to light up the light bulb. This will demonstrate that it holds the charge.
- Take apart a capacitor and explore how it is made

Links to everyday life

- The Leyden Jar is a primitive form of a capacitor. Capacitors are used in all kinds of complex electronics including computers and cameras. A capacitor is based on the same principle as the Leyden Jar. It has two sheets of metal foil that are separated by an insulator. Capacitors are very tightly wound so even a thimble sized one can contain many square meters of foil.
- Cameras are a really good use of a capacitor. Not enough power is supplied straight from the battery so it needs to be built up first. The capacitor acts as a storage device for the electrical energy needed to flash.
- Van de Graff generators use friction to build up a large static charge similar to how students rub the wool on the polystyrene.

Related Museum Galleries

- Do Not Touch (Energy Gallery)
- Materials that protect the body (Materials)
- Silicon Semi-conductors (Unusual Materials)
- Jumping Ring (Launchpad)

Curriculum Links

Key stage 3:

- Electrical energy transfer to components
- Critically analyzing and evaluating evidence from observations and experiments
- Energy can be usefully stored or dissipated but cannot be created or destroyed

The Science behind the Activity

When you rub the wool against the polystyrene, electrons are transferred from the wool to the sheet of polystyrene. The polystyrene becomes negatively charged as more electrons build up on it. When the aluminium plate is placed on top of the polystyrene, the negatively charge polystyrene pushes the negative charges on the aluminium to the top. When you touch the aluminium plate, you receive a shock because the aluminium wants to neutralize its charge and uses your body to connect to ground which has a neutral charge.

When you instead touch a tab of the Leyden Jar to the plate, your body is used to complete the circuit with ground, but some of the charge gets trapped in the jar. The section of foil that touched the plate becomes negatively charged as electrons transfer to it from the plate. The plate should now have no charge on it. The other section of foil that you keep your finger on becomes positively charged as the negatively charged section pushes its electrons away from it. As long as the two sections do not touch, the charge will remain for some time.

When you light up the light bulb, the Leyden Jar discharges its entire charge into the light bulb. The bulb lights since the static charge just like electricity from a wall socket. It discharges quickly so it only lights for an instant.

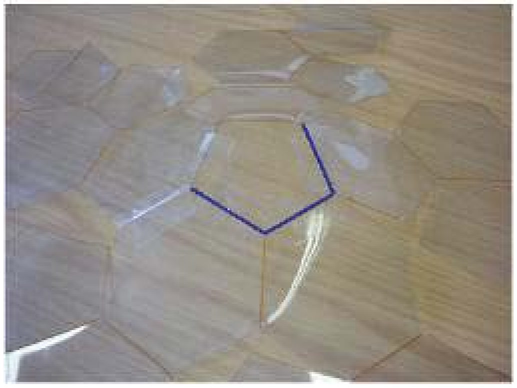
Appendix I: Biodome Assembly Instructions

The blue lines in the directions show which edges are connected in that step of the directions.

1. Place the biodome plastic sheet with the "This Side Up" sticker facing in the correct direction. It is easiest to work from the center out. Begin with the center most pentagon that has the sticker on it.

2. Securely tape the edge of the pentagon that is closest to the pre-attached edge to one of the surrounding hexagons. Line up the two edges as close as possible to avoid gaps or overlap.

3. Going in a counterclockwise direction. tape the remaining edges of the pentagon to its adjacent hexagons until all its sides are attached. It should rise off the ground as shown.



4. Tape the two hexagons that are not already attached in the next outer ring together to complete that ring.

5. The next ring is the tricky part. Start with one of the pentagons in the ring as shown below.

6. Tape the edge above the pre-attached edge. Be careful to avoid any overlap as this will complicate taping the remaining edges.

7. Going in the counterclockwise direction, tape the three following edges of the pentagon.

8. Tape the other pentagons in that ring in the same fashion as above.

9. Now for the last ring. Tape the trapezoid at the bottom to its neighbor.

10. Tape the rest of the trapezoids in this ring and fold the bottom tabs out to support the biodome and you are done!